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Instruments

THE MAGAZINE of MEASUREMENT and CONTROL

VOL. 23 | JUNE, 1950 | NO. 6

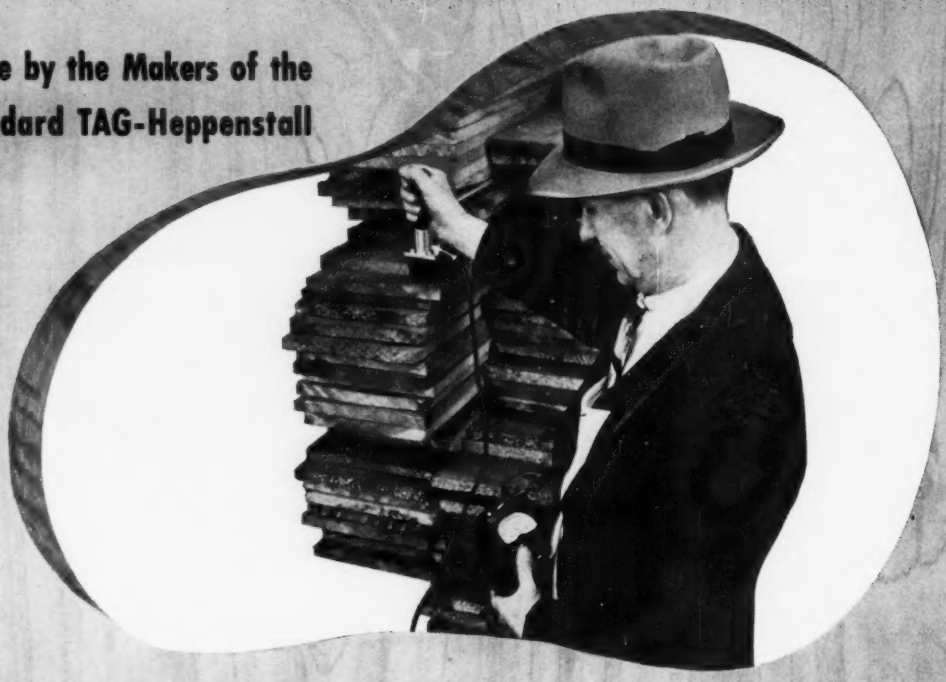
INCLUDING THE *Journal of the Instrument Society of America*

AND THE *Journal of the Southern California Meter Association*

Drill-press Dynamometer at the Metal-cutting Research Laboratory, Massachusetts Institute of Technology. **(See article on page 560.)**

NEW TAG midget moisture meter

Made by the Makers of the Standard TAG-Heppenstall



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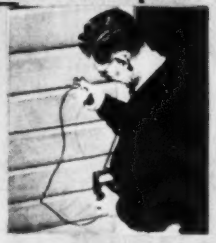

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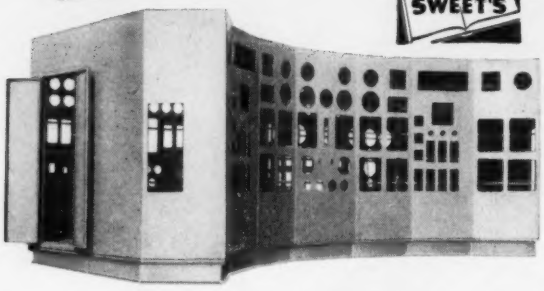

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Instruments

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EDITORIAL

By M. F. BEHAR

Electric Power Re-enters Servo Race

Gets an Assist from Good Old Mechanics

ONE of the reasons why Instrumentation fascinates all of us may be found in the big-league and minor-league contests that go on incessantly. Some are relatively slow-like marathons, or tugs-of-war. Years elapse before the advantage passes from one team to another. (Example, the race for "Most Stable Amplifier"

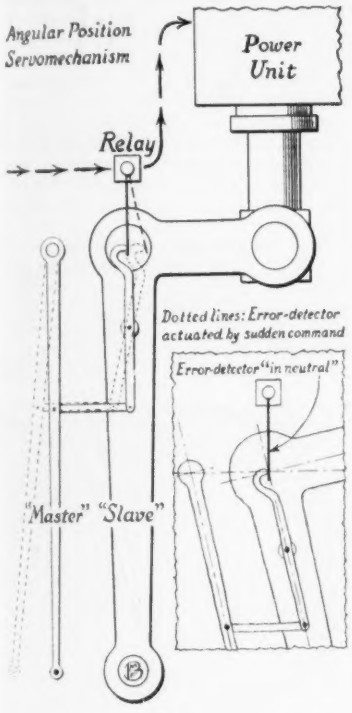


Fig. 1.

where most entrants have been neck-and-neck for nearly two decades.) Some contests are relatively fast—like squash or jai-alai. You have to read your favorite magazine every month to know what teams are ahead. And you've got to read it attentively, because the big news of important sports events may be hidden in brief items from instrument firms or research labs. One of the reasons is the characteristic modesty of Instrumentation competitors; another reason is that, in many cases, the fellow that suddenly forges ahead in one race doesn't know he's in line for several other trophies.

Of all the races being run, you'll probably agree that the most exciting is the one where the contestants are *the various forms of auxiliary power.* This is not merely one race but a big track meet, some of the races being "cost," "weight," "maintenance," "liveliness," "cleanliness," "safety," etc.

Until recently, electric power held last place in the "liveliness" race, which many persons consider the most important. "Liveliness" can be described as the speed with which the "slave" is able to carry out the commands of the "master" (see Fig. 1). One technical definition is the time for the power unit to reverse from full speed in one direction to full speed in the other. A more precise definition is the *characteristic time* (or "time constant") which is the time for the power unit to come up to 63.2 percent of full speed.

Until recently, hydraulic servomotors were reported to be a little more lively than pneumatic servomotors and about

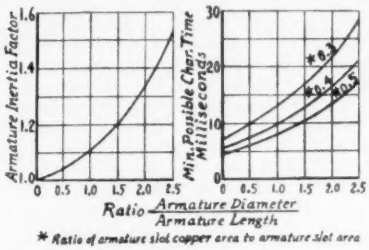


Fig. 2.

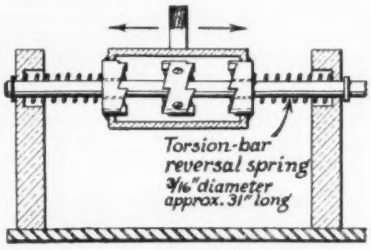


Fig. 3.

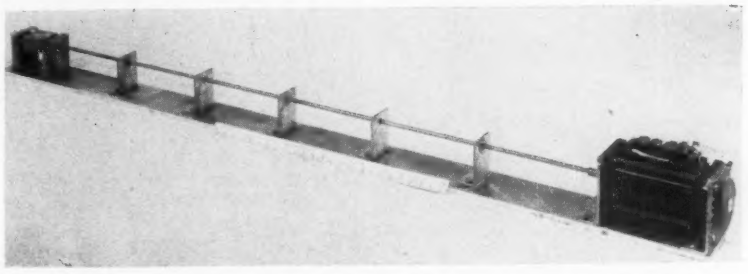


Fig. 4. NBS quick-reversal "breadboard." With the motor operating in either direction at 3200 rpm., the second of the two positive unidirectional clutches at the left end of the 31-inch steel torsion bar is engaged, thus stopping the rotation of the adjacent end of the bar. The kinetic energy of the motor is converted into potential energy in the torsion bar by approximately 20-degree additional rotation of the motor, and used to accelerate the motor rapidly in the opposite direction.

ten times as lively as electric servomotors. However, rumors were being whispered about military d-c. motors the size and shape of fountain pens, capable of reversing from thousands of rpm. clockwise to an equal speed counterclockwise in a small fraction of a second.

Last October the electric entry made a big spurt in the liveliness race when Paul Lebenbaum, Jr., of G-E, presented his paper on "D-c. Motors for Automatic-control Systems" at the AIEE Fall Meeting. Maybe it was the unwrapping of the wartime secret at long last; maybe not; but Fig. 2 shows what we believe to be the heart of Lebenbaum's disclosure. (For full details see the full text of his paper in the 1949 *Transactions AIEE.*)

Hydraulics and pneumatics were still ahead when, a few weeks ago, the National Bureau of Standards disclosed a radically new method which closes the gap between the electric and pneumatic runners and perhaps will put electric power ahead of the other two contestants. Figs. 3 and 4 show an experimental embodiment of the NBS method; Fig. 5 has been drawn from NBS data (which were *not* in terms of rpm., so that we assume responsibility in case it's not 100 percent accurate) and it shows conclusively that the liveliness of the secret motors (if they ever existed!) has been outdone. For this remarkable development, instrument users can thank Dr. Jacob Rabinow—the same NBS scientist who invented the magnetic-fluid clutch announced by the NBS two years ago (and fully described, with 14 illustrations, in our August 1948 issue, pages 756-764). For a complete description of the new high-speed reversal method see the NBS *Technical News Bulletin,* May 1950, page 63.

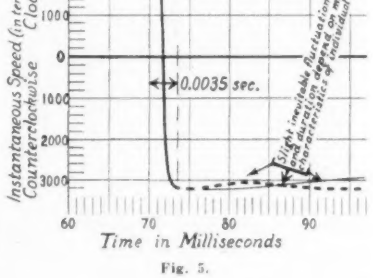


Fig. 5.

Instrumentation *and* Auxiliary Equipment *for* Automatic Infrared Gas Analyzers

By WILLIAM J. HAPPEL and NORMAN D. COGGESHALL,
Gulf Research & Development Co., Pittsburgh, Penna.

IN the development of petroleum processes from their pilot unit operation the continuous-flow infared gas analyzer[1,4,5] offers a new and powerful tool. When correctly adjusted to a pilot process gas stream, the continuous record of such an instrument effectively creates a window into the process reaction by giving an instantaneous visual indication of the control gas concentration. Sudden variations or sharp peaks in stream concentrations, normally missed by most spot sampling techniques, are immediately indicated and, as is important in such cases, located in a time record with the variation in the process temperatures, pressures or other variables. Normally, the value of such a visual presentation is further enhanced by a greater instrument sensitivity (to extremely low control gas concentrations) than can be obtained in the standard analysis of spot samples. Therefore, the use of the instrument calibration with the continuous concentration record permits a far greater over-all accuracy in material balance calculations than previously possible.

In addition to these advantages in the preliminary investigation of a process operation, the analyzer may be operated also as a monitor or automatic controller to maintain a desired level of gas concentration once a set of operating conditions has been chosen. This may be readily done either through an alarm system to the unit operators or in a completely automatic manner by direct control of the appropriate process valves or other operating parameters.

Some typical applications of this type of instrument are: the continuous determination of carbon monoxide and carbon dioxide in flue gases[3]; the monitoring of the sulphur dioxide concentration in a stream also containing nitrogen, hydrogen, and hydrocarbon gases; the determination of the methane concentration in a stream containing other hydrocarbon gases; and the determination of ethylene oxide in the catalytic oxidation of ethylene gas.[2]

These examples are just a few of the many problems that can be and have been solved by the continuous-flow infrared gas analyzer.

A primary limitation of the instrument is that it cannot analyze for infrared inactive gases such as the monatomic and symmetrical diatomic ones. However, for mixtures of infrared-active gases, a satisfactory operation may be achieved in many cases suffering optical interference by the judicious use of gas blends in the compensator and interference cells.

In such applications of the instrument, it has been found that to be of optimum advantage the analyzer should maintain its sensitivity and accuracy while having a simplicity of operation and a ruggedness that gives a freedom from all but minor maintenance. This article concerns the construction of a continuous-flow analyzer for pilot plant operation with the above principles as primary requirements.

General Construction

Fig. 1 shows the front view and general construction of the complete instrument. All components of the analyzer—including the gas handling equipment—are assembled in a standard closed relay rack which is mounted on a rubber-tired dolly to permit ease in moving the instrument. The infrared analysis of the stream originates in the thermostated optical compartment occupying the lower section of the relay rack. The chief component in this compartment is the optical tank which was purchased from Baird Associates Co., of Cambridge, Mass., and contains the infrared source, absorption cells and bolometer detectors. The thermostated compartment is sealed by rubber gaskets on the doors (as are the bridge control chassis and recorder case) so that a low positive pressure of instrument air may be maintained within it to prevent formation of gas pockets and reduce explosion hazards. The compartment is also insulated so that it may be maintained at about 120 F. to eliminate the effect of ambient temperature drifts. This is very important for the successful operation of the instrument.

The temperature regulation is effected by a mercury thermometer type electrical thermoregulator mounted alongside the optical tank. A change in temperature of 0.1 F. at the thermoregulator will actuate a mercury relay located at the rear of the gas control

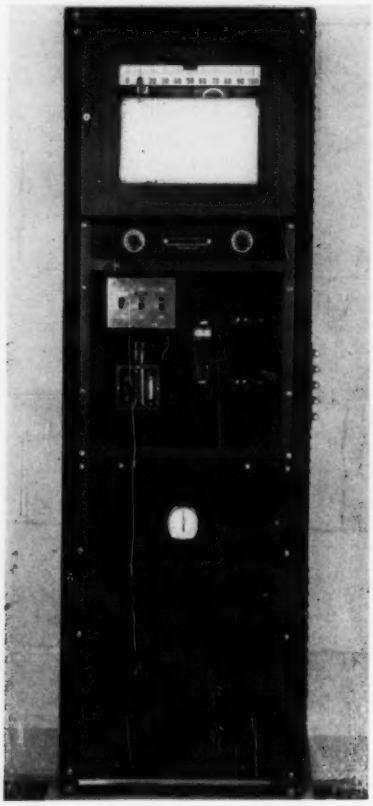


Fig. 1

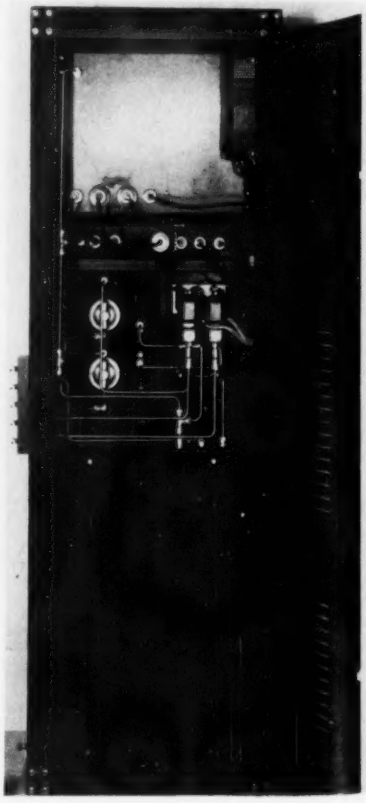


Fig. 2

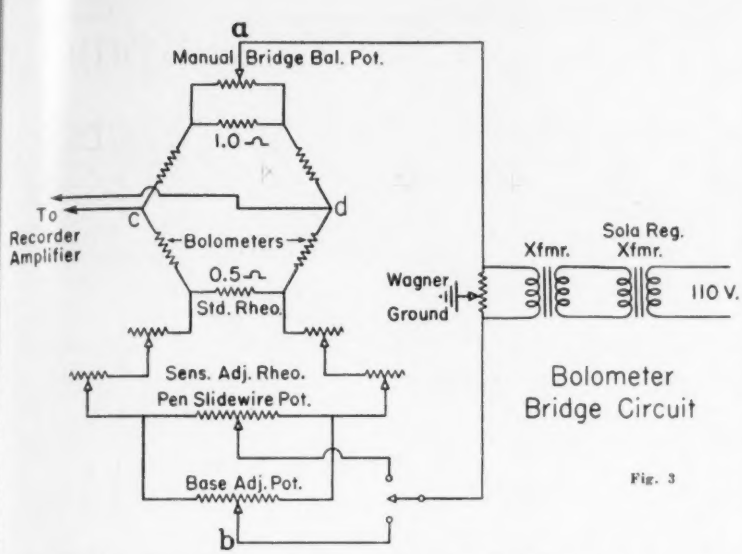


Fig. 3

panel, turning on or off a set of heaters mounted in front of a small continuously-running circulating fan. The internal temperature of the compartment is indicated by a dial thermometer on the front door just below the heater pilot light indication.

The thermostated compartment is readily accessible from the front and rear through hinged doors. This facilitates the maintenance and adjustment of the components housed in the compartment. Fig. 2 shows the mounting of the recessed gas control panel and some of the cabling and stainless-steel tubing used throughout the instrument. This style of cabling permits the removal of any or all of the individual units for bench testing; the stainless-steel tubing permits application of the instrument to corrosive gas streams.

All input power is through a single Amphenol connector. Power for the Brown recorder amplifier, the source and the bridge circuits, is supplied from a Sola voltage-regulating transformer mounted at the rear of the recorder. The main power switch and the auxiliary electrical gas-handling equipment controls are located on the recessed gas control panel just above the thermostated compartment. The auxiliary gas handling equipment also mounted on this panel includes the stream flowmeter, stream-pressure mercury safety valve, and the instrument air and process stream regulators.

To maintain simplicity of operation, the bridge control chassis, mounted just above the recessed gas control panel, was designed so that the only adjustments available for normal operator use are the bridge base line control and the sensitivity adjustment or scale expander rheostats. The gasketed Bakelite instrument label located at the center of the chassis may be removed in instrument servicing for access to the source and test signal switches. This latter switch creates a predetermined bridge unbalance with a consequent error signal that is independent of the infrared beam absorption for the examination of the instrument signal circuits. The adjustable Wagner ground, used to minimize stray pickup in the bridge circuit and associated cabling, is mounted on the rear of this chassis and protected after adjustment by a knurled cap covering the shaft.

Electrical System

A Brown "Electronik" strip-chart recorder with a 4½-second full-scale pen speed and a high-gain high-impedance amplifier was modified for operation with the bolometer bridge circuit. The input converter to the recorder

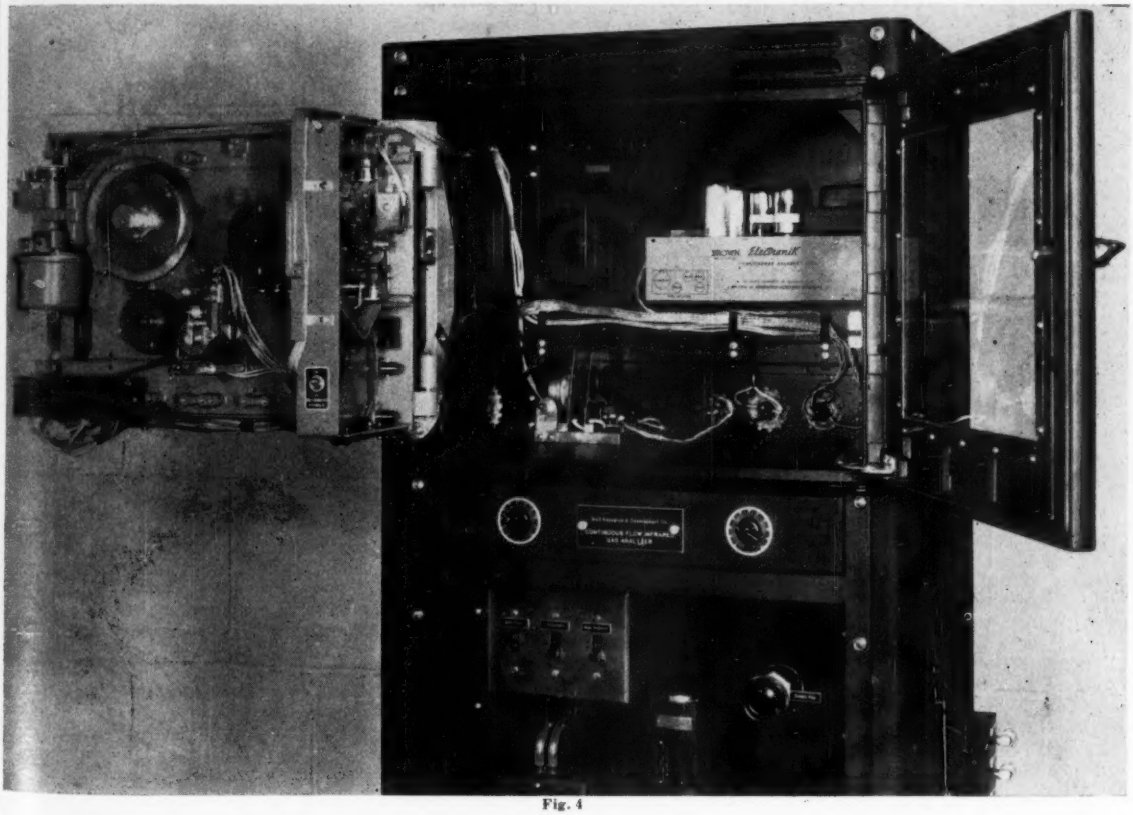


Fig. 4

amplifier was by-passed and the a-c. bridge error signal fed directly to the first stage of the amplifier through an input transformer. The standard cell and the associated Brown d-c. standardizing circuits were removed from the recorder to permit the rewiring of the pen slidewire with the Brown standardizing battery rheostats and switch into the bolometer bridge circuit as shown by Fig. 3.

In this circuit the pen slidewire is a shunt on the small 0.5-ohm bridge resistor. As the pen is moved, the slidewire potential-dividing resistor is rotated and effectively transfers part of the 0.5-ohm shunt from one bolometer arm to the other in such a manner as to maintain bridge balance. The system of variable rheostats connected in series with this slidewire is for automatic standardization and for instrument sensitivity control.

The automatic standardizing circuit used here is well-known and has merely been adapted to operation with the Brown Recorder. The standardizing rheostats are tandem-mounted so that the sum of their resistances will be maintained at 30 ohms. As one rheostat has more of its resistance cut into the circuit, the resistance of the other rheostat is equally reduced. The effect of rotating their shaft is to shift the curve which the pen traces either to the right or left since the pen slidewire will now have to be moved to maintain the original bridge balance conditions. Such a correction as this is required if there has been a small drift in the base line is subject to a drift which is corrected automatically once every hour by the injection of nitrogen or instrument air to obtain zero stream concentration and followed by the subsequent adjustment of the standardizing rheostats to maintain the original base line setting. To obtain this operation, a 1-rph. clock motor drives a set of cams (see Fig. 4.) one of which triggers a Microswitch operating the relay cutting off the stream flow and turning on the nitrogen. The nitrogen flows through the sample cell for about two minutes. Then a second cam triggers its Microswitch to operate a small relay energizing the standardizing mechanism. The original recorder standardizing mechanism could be triggered automatically by a gear train from the chart-drive motor or manually from a push-rod on the front of the recorder. In this particular application the triggering spur on the gear train was removed and a small relay was mounted so that on closure its armature would operate the manual push-rod. When this relay is energized, the clutch is released on the standardizing battery rheostats, permitting them to be driven by the balancing motor. At the same time, the movement of the clutch will throw a switch which removes the recorder slidewire from the circuit and substitutes another potential-dividing resistor (the base selector resistor located at the top of the recorder) that has been previously adjusted manually. If, because of some drift, the base-line to which the pen return is not the correct one, there will be an error signal when the clutch is thrown which will drive the standardizing rheostats in such a direction and through a sufficient distance to restore the original base-line position of the pen.

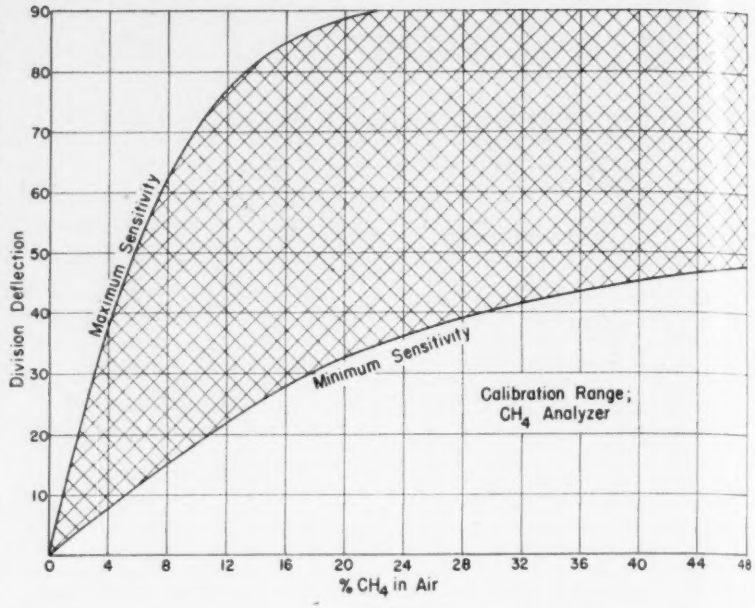


Fig. 5

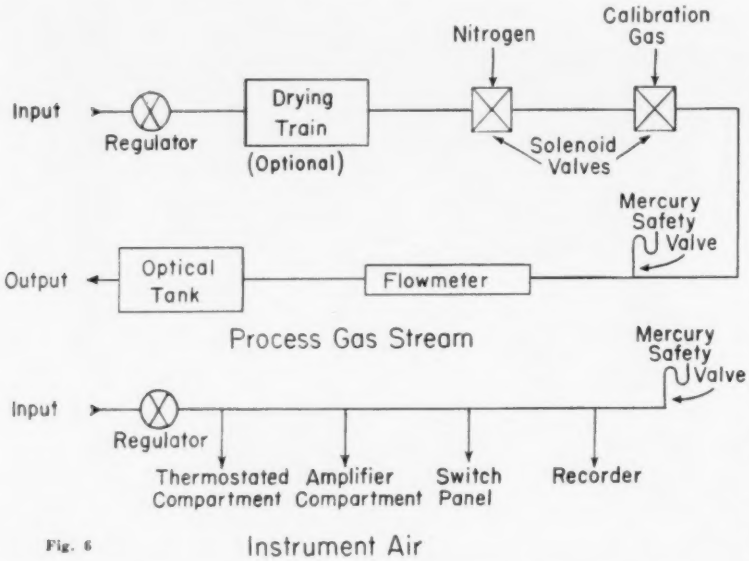


Fig. 6

The sensitivity adjustment resistances are also matched tandem-mounted rheostats. They are, however, manually operated and so connected that each rheostat will turn in the same amount of resistance per unit angle shaft rotation. When this shaft is turned so that the resistance of the sensitivity adjustment rheostats is zero, the maximum variation of the pen slidewire would mean a fractional change, to first approximation, of 0.005 of a bolometer arm resistance, omitting, for simplicity, the resistances of the standardizing rheostats. On the other hand, with the maximum resistance of the sensitivity adjustment rheostats turned completely in, the same variation of the pen slidewire would now give only a fractional change of approximately

$$(0.5/1000) \times [R_3/(R_1+R_2+R_3)]$$

operating points of the bridge bo.ometers or any other change which temporarily unbalances the system without changing its calibration significantly.

A point on the recorder chart, near the left edge, corresponds to zero concentration in the stream. The pen left at this point will trace out a base line which may be changed arbitrarily by adjusting the bridge balance control, Fig. 3, fixing the initial bridge balance.

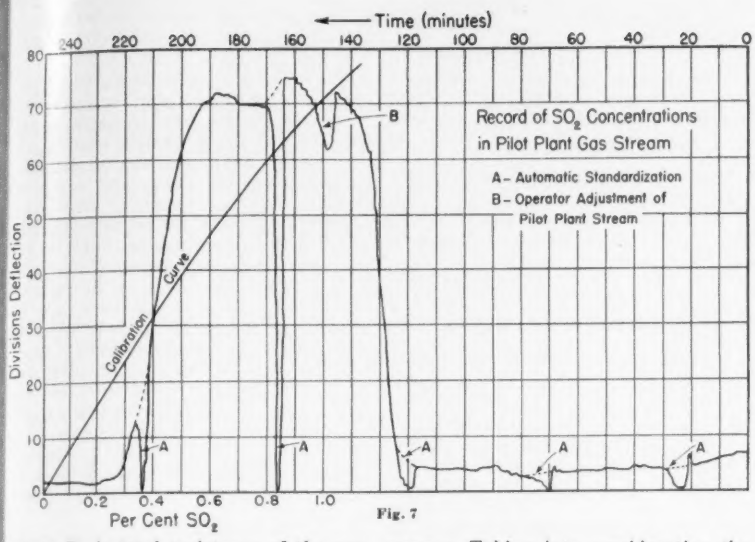

Time (minutes)
240 220 200 180 160 140 120 100 80 60 40 20 0
Divisions Deflection
Record of SO_2 Concentrations in Pilot Plant Gas Stream
A – Automatic Standardization
B – Operator Adjustment of Pilot Plant Stream
Calibration Curve
A
B
Per Cent SO_2
0 0.2 0.4 0.6 0.8 1.0

Fig. 7

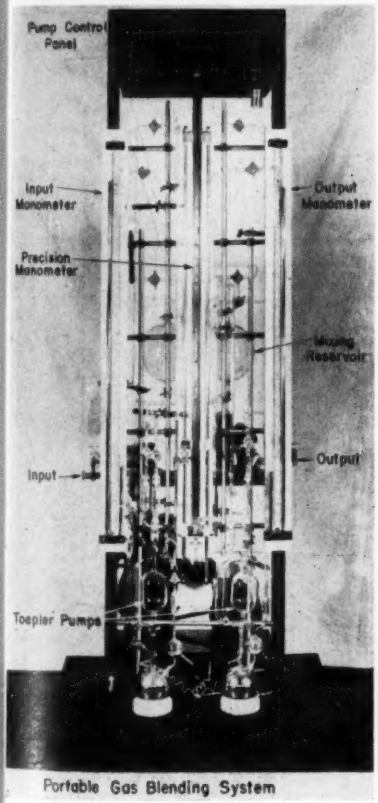
where R_3 is total resistance of the pen slidewire and R_1 and R_2 are the resistances of the sensitivity adjustment rheostats. Hence, for a given bridge unbalance signal, the amount of movement (pen deflection from base line) in the pen slidewire required to bring the bridge back to balance will be $(R_1+R_2+R_3)/R_3$ greater for the latter case where $R_1=R_2=$ maximum than for $R_1=R_2=0$. For sensitivity scale changes, this control was made to give a range of about 3 to 1 in a continuous manner. Taking into consideration the value of the standardizing resistances and the base-line adjustment potential dividers, this amounted to a transfer of 0.24 ohm to 0.09 ohm for a minimum to maximum variation of the sensitivity adjustment control on a full-scale pen deflection.

Such a control is of great use to the pilot-plant operator in the correction of the slow decay of instrument sensitivity and the elimination of instrument recalibration. If, for example, the operating concentration of the component in the process stream should give a one-inch deflection for the condition of minimum sensitivity adjustment resistance, and if a fogging of the sample cell lenses or slight gas leak should occur (which would result in a sensitivity loss) it is now possible to maintain the original calibration without instrument shut-down or recalibration. In addition, it is possible to adjust the control to obtain a three-inch deflection for the same concentration in order to magnify any minor changes in the process stream. This control has been found quite useful also where different unit streams on the same problem have different levels of the desired component concentration. Fig. 5 shows the possible sensitivity range obtainable by the sensitivity adjustment control.

The bolometer detectors are located in a standard Wheatstone bridge circuit energized from a step-down transformer across points a-b, Fig. 3. The bridge may be balanced manually by the bridge balance control located on the bridge control chassis. The error signal caused by variations in the product stream concentrations is applied to the amplifier input transformer in the recorder through a short length of shielded two conductor cable to drive the balancing motor and coupled pen slidewire in such a direction as to return the bridge to balance. A Wagner ground was used across the bridge source to minimize the stray pickup in the bridge circuit and associated cabling.

Gas-handling System

Fig. 6 shows the schematic diagram of the analyzer gas-handling system including both process stream circuit and instrument air pressurization lines. Stainless steel quarter-inch O.D., $\frac{3}{16}$-inch I.D. tubing with Ermetto type fittings was used throughout the instrument to eliminate corrosion. The base line register solenoid, which cuts off the stream flow and flushes the system with nitrogen, is operated by the cam-tripped Microswitch driven by the 1-rph. clock motor. This solenoid may also be tripped by a manually-operated mercury switch on the gas-control panel below the recorder permitting a nitrogen flush of the sample cell at the will of the operator to register the base



Portable Gas Blending System

Fig. 8

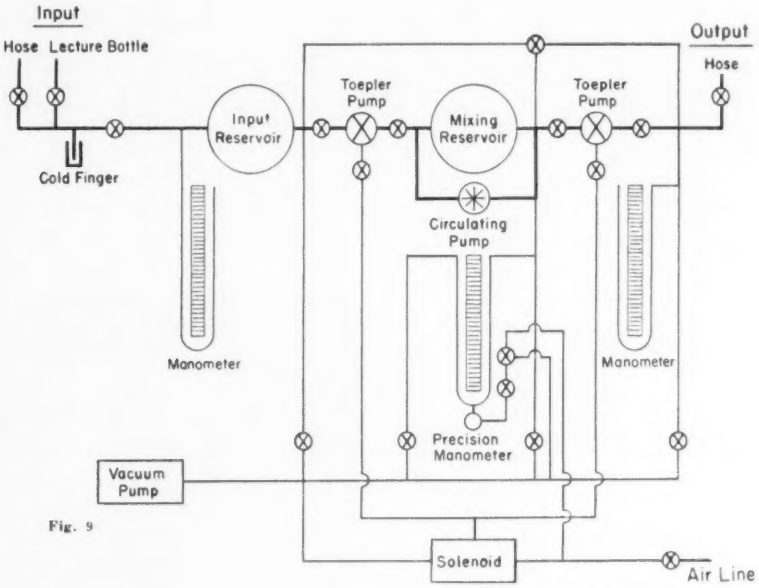


Fig. 9

line. The adjacent switch permits the injection of a standard gas blend to calibrate the instrument. A second solenoid valve, but no relay, is employed in the sample line to accomplish this. The solenoid valves (Automatic Switch Co. P32X) are of the three-way type, connected with the stream passing through to the sample cell in the optical tank when they are in the unenergized position. When either valve is energized, the stream is turned off and the appropriate gas, either nitrogen or the known blend, passes through a regulator from its storage tank to the sample cell.

The normal calibration check procedure requires: first, throwing the baseline register switch to establish the base line, with the nitrogen flush, and then the calibrate switch for the injection of a known blend. After the pen has indicated the final deflection, both switches may be turned off and the instrument returned to the stream gas.

A flowmeter (Fischer & Porter No. 180) is inserted between the valves and the sample cell, when the float is at about 4 on the scale of the flowmeter, the flow rate is about 1 cfh. At the stream input to the instrument, there is a Conoflow diaphragm regulator to reduce the line pressure to a few inches of water pressure. Between the flowmeter and the optical tank, a mercury safety valve diverts the stream to the room in the event of regulator maladjustment or failure and thus prevents excess pressures in the optical cells. All of these components on the stream are located on the gas-control panel in full view of the operator.

The instrument air stream, used to prevent combustible gas pocketing in the compartments, is regulated by a Conoflow diaphragm regulator. As in the process stream, a mercury safety valve is used after the regulator to prevent excessive pressure in the instrument compartments in case of an accident. Normal instrument air pressure is about a quarter-inch mercury column.

Operation

The continuous-flow infrared gas analysis of process streams is satisfactorily achieved by the type of instrument described. Fig. 7 demonstrates a typical recorder-chart record obtained when the instrument was applied to the determination of the SO_2 concentration in a process stream. The instrument calibration curve has been superimposed on the tracing of the recorder chart, showing that for this run the peak SO_2 concentration was of the order of one percent. Knowing the flowrate of the process stream, the total SO_2 generated by the unit can be determined from the area under the curve. For this use, it would be necessary to extrapolate the curve as shown by the dashed lines at the standardizing points A. It is necessary, however, that all the components of the analyzed stream be known and the possibility of interference effects investigated and eliminated. This can only be satisfactorily done by the use of mixtures of known composition. In order to readily investigate the range and sensitivity of the instrument described above, a portable gas-blending system was constructed as shown in Fig. 8.

Gas-blending System

This system permits the precise blending of synthetic gas mixture up to two liters at atmospheric pressure. This is done by successively inserting individual components into the same volume and then computing the concentration from the corresponding pressure changes in the constant volume.

The gas-blending system as shown is constructed of glass. A schematic diagram of the system appears in Fig. 9. In operation, the general procedure is to evacuate the system and admit a pure gas from the tank manifold (upper left in the schematic) to the input reservoir. The gas is transferred by the Toepler pump to the mixing reservoir. The input reservoir is then evacuated and the next component gas admitted. After all the desired components have been introduced into the mixing reservoirs and their partial pressures determined, the gases are thoroughly mixed by the action of a circulating pump which moves the gases in and through the reservoir. The blend may then be transferred to a sample receiver by the second Toepler pump. The Toepler pumps are automatically cycled by delay circuits so that no sparks occur within that part of the pump containing the gas blend—to eliminate the danger of explosions with flammable mixtures.

A Welch "Duo-Seal" rotary vacuum pump serves to evacuate the system and sample receiver before a blend is made. During the blending process, this same vacuum pump operates the mercury displacement arrangements used to transfer gases into and out of the blending reservoir and also to control the mercury content of the precision manometer on which the blend pressure is read.

The mixing of the blend, which is necessary to obtain homegeneous mixtures and reproducible calibration data, is obtained by a sealed centrifugal type pump. The pump was constructed by increasing the air gap of a 4-pole 1/80-hp. Alliance induction motor to permit mounting of the motor armature in Oilite type bearings within a thin-walled brass housing sealed at one end. The field from the pole shoes penetrates the brass to obtain armature torque, driving the armature at about 25 percent slip. A three-inch centrifugal type impeller supplies the necessary pressure differential to give circulation within the mixing reservoir. Kovar glass seals are used for the bond between the glassware of the system and the metal of the impeller housing and, by using a ring seal, a good vacuum can be maintained.

Acknowledgment.—Acknowledgment is gratefully made to Dr. Paul D. Foote, Executive Vice-President of Gulf Research and Development Company for permission to publish this material.

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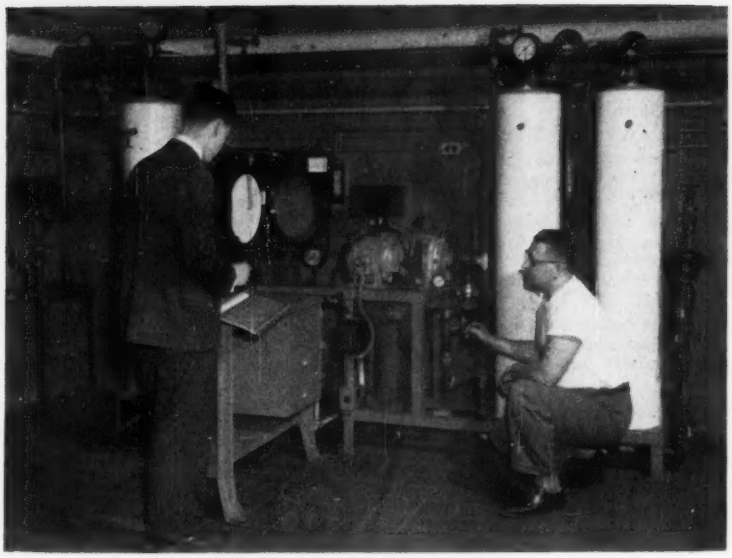
Instruments' Publisher in England

Richard Rimbach, President of The Instruments Publishing Co., returned from his six-week Western Europe trip shortly before this issue went to press. His articles will start in our July issue. This photograph shows him (gray suit, center) at a reception for publishers given by the Council of the Radio & Electronic Component Manufacturers' Federation at Grosvenor House, London, on April 17.



Control of Water Heating Process. Different process characteristirs are possible by changing valves on the two thirty-gallon tanks. A pump is used to circulate water between the tanks and a steam heater below the pump.

The Teaching *of* Process Control Principles *To* Chemical Engineers

By JOSEPH B. GRAY, Assoc. Prof., Chemical Engineering Dep't, Syracuse University, Syracuse, N. Y.

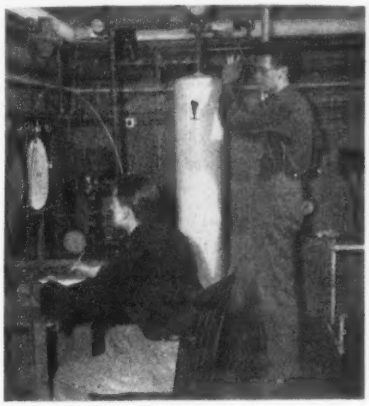
COURSES in the principles of measurement and automatic control appear in the curricula of a large fraction of the fifty accredited Chemical Engineering schools. However, many of these courses were only recently organized and there is much to be gained by an exchange of experience and a discussion of the problems involved in teaching such a course. In this article are presented an outline of the course taught at Syracuse University and a discussion of factors involved in organizing lectures, classroom problems and laboratory problems.

A three-semester-hour course is required of all Seniors in Chemical Engineering at Syracuse University. The course consists of two lectures and one three hour laboratory per week for one fourteen week semester. "Industrial Process Control" by Eckman is used as a textbook to supplement the lectures and "Instruments and Process Control" by the New York State Vocational and Practical Arts Association is used in connection with the laboratory work.

The primary purpose of the course is to develop an understanding of the behavior of typical processes or systems when controlled automatically. It is felt that a knowledge of *what* takes place in a process under automatic control is not enough and that, as far as possible, the *reasons* for what takes place should be presented. For this reason the principles explaining the behavior are described in this course and applied to typical problems arising in the automatic control of various processes. The scope of the principles described in the course is indicated by the following questions for which answers are sought:

a. Why control a process?
b. What is automatic control of a process?
c. What devices are available for measurement and control and how do they function?
d. What factors influence the behavior of a controlled process and in what way?

The factors influencing the behavior of automatic control systems are emphasized. The effect of disturbances, delays in corrective action and characteristics of controller, measuring element and control valve on the stability of control and magnitude of deviations from the control point are considered in detail.



Equipment for studying control of air pressure.

The effect of process characteristics on the behavior of a controlled system are described in terms of the components of unsteady-state energy and material balances. Such balances define the rate at which a variable can change in a process and this rate, in turn, has a great effect on the stability of control of that variable.

Outline of Course

The organization of these topics that is used in lectures to Senior Chemical Engineering students is shown in the accompanying outline.

I. *Introduction*
A. Necessity for control of processes
B. Description of a simple automatic control system
1. Essential parts
2. How control is effected—causes and correction for deviations of controlled variable
C. Typical problems arising in automatic control of processes.
II. *Process Characteristics*
A. Rate of change of variables and factors affecting these rates.
1. Single-capacity processes for control for temperature, pressure or level.
2. Multiple-capacity processes.
B. Self regulation.
C. Characteristics of typical processes.
III. *Behavior of Automatic-control Systems*

for controllers possessing two-position, proportional, reset or derivative response.

A. Typical behavior of variables in control systems.

B. Construction and operation of typical controllers.

C. Effect of variables on stability of control and offset.

1. Rate of change of variable controlled.
2. Disturbances in flow to or from process.
3. Controller adjustments.
4. Control valve and valve positioner adjustments.
5. Measuring element characteristics.

IV. *Characteristics of Measuring Elements for temperature, pressure, differential pressure, flow, liquid level, pH, etc.*

A. Construction.

B. Principles of measurement.

C. Sources and magnitude of delays in response.

V. *Characteristics of Final Control Elements*

A. Construction and operation of typical valves and valve positioners.

B. Relationships between air pressure, valve position, valve area, and flow through diaphragm control valves.

C. Delays in response.

D. Selection of valve size and characteristics.

VI. *Typical Automatic-control Systems*

A. Simple processes in which temperature, pressure, liquid level and flow are controlled.

B. Complex processes

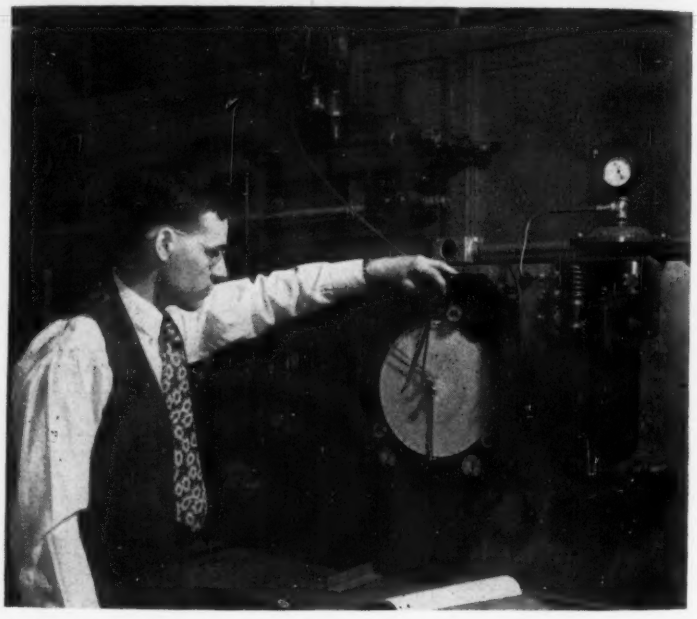
1. Metered control, ratio control.
2. Distillation, combustion, steam generation, etc.

The introductory material includes a discussion of the economic factors necessitating utilization of automatic control in most industrial processes, a brief description of the parts of an automatic control system and of the factors affecting the behavior of a relatively simple control system. In addition, typical design and operating problems arising in automatic control practice are described.

A general picture of the subject and its application is presented in this way, which should help in providing the student with a skeleton which can be filled in later with a detailed description of the various aspects of theory and its application.

Following this brief survey of automatic control, a detailed consideration is given to the characteristics of processes which are significant in the control of the process. It is the process with which automatic control is primarily concerned and the controller, measuring element and control valve characteristics modify the process behavior to obtain the desired end. The characteristics of the control devices are superimposed on those of the process. A knowledge of the transient behavior of processes in which an energy or material balance is sought is essential to understanding the behavior of an automatic-control system in which the process is a part. Differential equations are set up for simple processes and the factors affecting the rate at which the variable to be controlled changes are discussed in terms of these equations.

In a course on automatic control, it is desirable to describe as early as possible the behavior of typical control systems, including what variables influence this behavior and in what direction. The relative importance of each of the many factors which influence this behavior can then be seen more easily. For a larger fraction of the course the student will be thinking in terms of the relationships among the parts of an automatic-control system and their interaction. On the other hand, if a detailed consideration of the characteristics of the various parts of a control system is made first, then a coordination of all these details is delayed considerably. It is desirable to defer a detailed consideration of the characteristics of the parts of a control system until typical behavior of the whole system is made known to the student. Then the characteristics of each part can be studied in class and laboratory in terms of their effects on the behavior of the whole control system. Such a sequence of topics should develop more rapidly in the student a broad perspective of the subject.



Equipment for studying effects of control valve and valve positioner adjustments on control of air pressure.

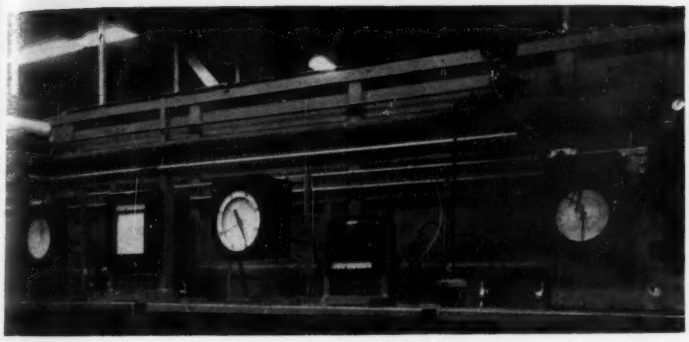
In describing the behavior of automatic-control systems, it is assumed that a disturbance of some kind causes the controlled variable to deviate from the desired limits of satisfactory control. Such a disturbance causes a change in supply or demand for energy or material and deviations from the control point. A detailed study is included of the effect of the nature of the disturbance on the behavior of the control system.

Following a description of the behavior of typical automatic-control systems, the characteristics of measuring elements and final control elements (valves) are considered. It is here that the reasons why these devices possess the characteristics they do are presented. In previous brief descriptions are mentioned what the characteristics are and not the theory behind them. For example, it suffices in describing the behavior of automatic-control systems to say that delays in response exist in measuring elements and control valves. Only a brief explanation need be given at that point. The details are developed later.

A description of the applications of controllers to typical industrial processes is placed last in the course. There is included then not only the principles of automatic control and measurement (and the application of these principles to typical problems) but also a description of what is usually done to obtain satisfactory control.

The principles behind the topics just discussed are relatively abstract and can require a knowledge of higher mathematics which few possess. However, an undergraduate engineering student can be equipped to handle a large fraction of automatic-control problems arising in the use of control instruments without a complete mathematical treatment of control theory. For this reason, the course for Chemical Engineers at Syracuse University does not include extensive development of the differential equations describing the behavior of controllers and processes. Furthermore, the mathematics of automatic-control systems which has been developed relatively completely for certain electrical and mechanical systems (servomechanisms) has not been applied to many of the processes in which Chemical Engineers are interested. There is an opportunity here for applications of this theory which will be very useful when it is available.

The possession of a knowledge of automatic-control principles by a student is not enough. Some knowledge of their application to control problems arising in the design and operation of a process is highly desirable. For this reason typical problems are discussed following the presentation of



Temperature and Pressure Recorders and Controllers.

principles necessary for their solution. For example, after unsteady-state material and energy balances, the selection of suitable variables for control of a process is discussed. Selection of controller characteristics follows the description of the behavior of automatic-control systems. Reduction of delays in corrective action can be discussed when the sources of these lags are presented. The means of correcting unsatisfactory behavior of a control system are available to the student in most cases when all the factors affecting their behavior have been discussed.

In order to counterbalance in part the abstract nature of the theory of control of processes, the devices used in control systems are described in this course when the characteristics of these devices are considered in detail. When discussing the behavior of a system in which a proportional type controller is used, it helps to have a mental picture of the parts of a typical controller and how the controller functions. The construction of various measuring elements and control valves is described for the same reason.

The factors affecting the control of a process receive more emphasis than the methods of measurement. The elements of calibration of measuring devices are included, however, because the values of the variable being measured in the control of a process are essential to an analysis of the performance of the process. The values may not be essential in the control of the process, however.

Classroom and Examination Problems

The selection of problems for quizzes, exams, classroom discussion or laboratory experiment is a source of difficulty in teaching process-control principles. The instructor must devise his own problems, and there is a wide variety in types of problems which can be devised. A few words on the relative desirability of the various types will assist in this selection.

Just as lectures should cover not only principles but also their application in typical problems, so should the class and examination problems be more than an exercise in the knowledge of abstract principles. Problems which require an application of these principles are preferable. Below are listed the types of problems which are suitable.

I. *Problems arising in design of processes.*
A. Selection of variables suitable for control of product quality.
B. Reduction of delays in corrective action of controller.
C. Reduction of disturbances and effects of disturbances.
D. Selection of control devices, including method of measurement and mode of control.

II. *Problems arising in operation of processes.*
A. Location of source of unsatisfactory control.
B. Adjustment of control devices.
C. Reduction of disturbances.
D. Reduction of delays in corrective action.
E. Calibration of measuring devices.

The scope of problems which can be devised, is shown by the above table to be relatively wide.

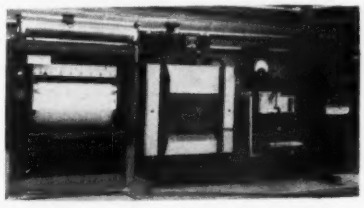
Laboratory Experiments

There is quite a variety of laboratory experiments that can be used by the students to supplement the lectures in a course on principles of control of processes. A broad classification of the types of experiments that might be devised is outlined below.

I. *Studies of the mechanisms of control devices, and how they operate.*

II. *Calibration of measuring elements.*

III. *Studies of the effect of control system variables on the behavior of the controlled variable.*



Electric Furnaces and Controllers. Either controller can be used with either furnace. The rheostat and "Powerstat" are used to vary the higher and lower heating rates of the control cycle.

A. Controller and control valve characteristics and adjustments.
B. Measuring element characteristics.
C. Process characteristics—including rate of change of controlled variable, and process lags.
D. Source, size and frequency of disturbances.

IV. *Illustration of typical control system behavior.*
A. Types of control stability.
B. Controller response for various modes of control.
C. Process reaction curves, transfer lag.

V. *Measurement of characteristics of controller, control valves and measuring elements.*

VI. *Correction of unsatisfactory control system behavior.*

VII. *Design of a control system, assembly and testing the performance.*

It is felt that the first three types of experiments will teach the most for the time spent. It is desirable to study quantitatively, where possible, the effect of the variables on the behavior of a controlled variable rather than merely illustrate what is typical behavior of a controlled variable. The means of correcting unsatisfactory control can then be more readily deduced using this point of view in presenting a picture of control system behavior. In addition to a knowledge of this behavior, some knowledge of the mechanisms, their operation and calibration is desirable. A more concrete and less abstract picture of automatic control systems is thereby obtained.

Much would be learned if the design of control systems were attempted by the students and the system constructed, tested and necessary alterations made to correct unsatisfactory performance. However, it is felt that laboratory problems of this type should be attempted only by graduate stu-

Furnace Temperature Control.

dents who are interested in research in this field for many of the techniques have not been developed.

The types of experiments which are being developed for use in the process control laboratory at Syracuse University are listed below. Those which are not yet being used are enclosed in parentheses.

I. *Thermocouple potentiometer, controller*—a study of principles of operations and methods of calibration.

II. *Pneumatic proportional-reset liquid expansion type temperature controller*—a study of principles of operations, and calibration.

III. *Pneumatic, proportional-reset-rate response, pressure controller*—a study of principles of operation and calibration.

IV. *Pneumatic, differential pressure flow controller*—a study of operation and calibration.

V. *Furnace temperature control, two-position, (floating) and proportional (reset)*—a study of the effect of process characteristics and controller adjustments on behavior of the control system.

VI. *Air pressure control, with proportional and proportional-reset response*—a study of the effect of controller adjustments and process characteristics on stability of control and offset.

VII. *Water temperature control with proportional and proportional-react-rate response*—a study of the effect of controller adjustments and process characteristics on stability of control.

VIII. *(Liquid level control with two-position, and proportional-reset response)*—a study of the effect of controller adjustments and process characteristics on stability of control.

IX. *Steam flow control with proportional-reset response*—a study of the effect of load changes, controller and control-valve adjustments on stability of control.

X. *Control valves and valve positioners*—a study of adjustments on behavior of an air pressure control system.

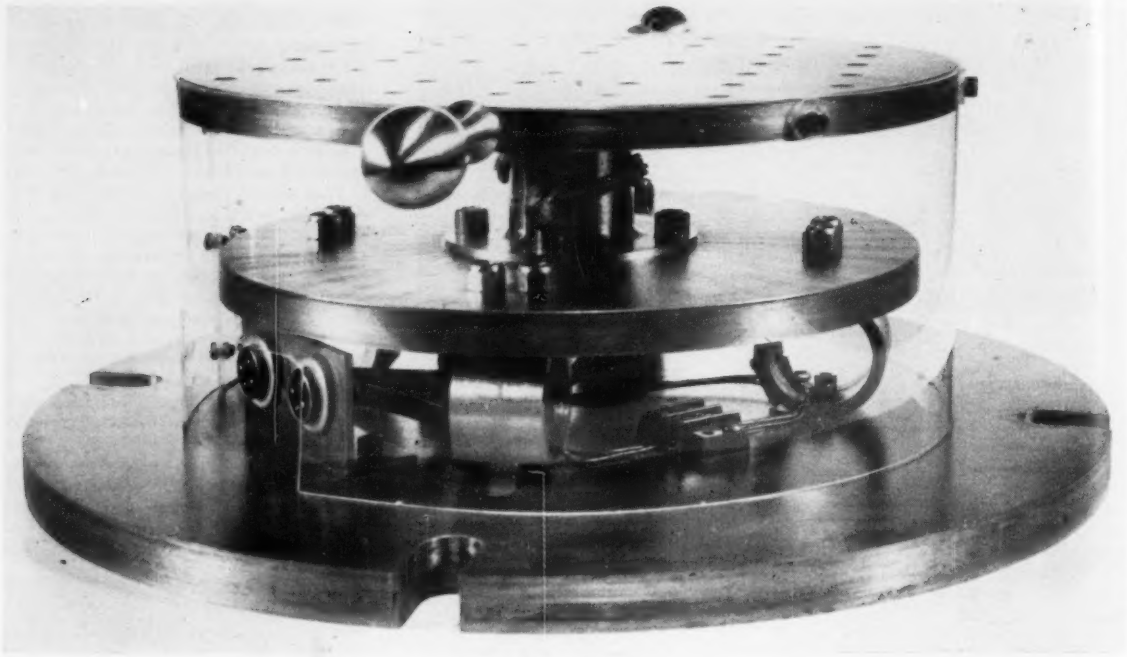


Fig. 1. Drill dynamometer

A Dynamometer *for* Measuring Forces *on a* Drill

By ERWIN G. LOEWEN and MILTON C. SHAW,
Metal Cutting Research Laboratory, Massachusetts Institute of Technology

DYNAMOMETERS have been used for a good many years to study the thrust and torque on drills, Bird and Fairfield having described an instrument as early as 1905. The major requirement of a drill dynamometer is that it be capable of measuring the thrust and torque reactions without mutual interference. In practically all of the earlier devices this was accomplished by use of a ball thrust bearing, this bearing being used to support the workpiece with as little angular restraint as possible. The underside of the bearing was supported by a suitable thrust-measuring element, such as a hydraulic cylinder, while the specimen was kept from rotating by a measuring device such as a spring scale or second hydraulic cylinder. In addition to the mechanical complexity of these devices, the ball bearings employed do not provide sufficient rigidity under the fluctuating loads encountered in drilling. Furthermore, there exists the additional possibility of dirt entering the bearings which may result in increased frictional errors.

The drill dynamometer described here (Fig. 1) has no loose or sliding elements and all the deflection taking place is purely elastic. By use of wire resistance strain gages the necessary deflections of the dynamometer elements are kept to a minimum. The dynamometer is built in two parts, the upper half being designed to measure torque but not thrust while the lower half is sensitive to thrust only.

The torque-measuring element, located between the upper and intermediate plates of the dynamometer, consists of a hollow cylinder with two flat surfaces milled on opposite sides. The purpose of these surfaces is to provide a localized area of high strain without greatly sacrificing the over-all rigidity of the unit. Two strain gages are symmetrically cemented on each of the flat surfaces and located at right angles to each other and at an angle of 45 degrees to the axis of the cylinder. When a torque is applied, two of the gages are subjected to tension while the other two are compressed an equal amount. By properly connecting these four gages in a bridge circuit the strain output resulting from torque is additive, while that resulting from direct compression due to thrust, and bending due to eccentric loading, is balanced out.

The thrust-measuring part of the instrument consists of four steel rings located between the intermediate and base plates. Two strain gages cemented circumferentially on each of the rings, one inside and one outside, are placed in compression and tension respectively when a thrust load is applied. The rings are so located that the effect of torque is entirely neg-

ligible. The eight gages attached to the rings are again connected into a bridge circuit having four active arms.

In the torque tube and in the thrust rings, the gages are so located and connected to provide automatic compensation for changes in the temperature of the instrument. The mechanical rigidity of the unit is unusually great in order to minimize vibrations and approach actual drilling conditions as much as possible. The torsional rigidity is 0.5 microradians per inch pound of torque and the thrust rigidity 3 microinches per pound of thrust.

The dynamometer was designed to be used with a Brush "BL 310S" Strain Analyzer (with four active arms) or with apparatus of similar sensitivity. With such equipment it is capable of measuring the performance of drills ranging in size from a quarter-inch to over one inch. At maximum gain the sensitivity is 1 mm. pen deflection of the oscillograph for a thrust load of four pounds or a torque of 2.5 inch pounds. The maximum design values were 2000 inch-pounds torque and 5000 pounds thrust, and this allows for a factor of safety of four. Thus under ordinary conditions a drill will break before the dynamometer is overloaded.

Representative data obtained by use of a Brush Strain Analyzer are shown in Fig. 2 for drills of 0.25, 0.5 and 1 in. dia. The feed was the same (0.009 inch per revolution in each case) but the speed was adjusted to approximately 30 feet per minute in each instance. The traces of thrust and torque at equilibrium are seen to be more uniform for the quarter-inch and half-inch drills than those for the one-inch drill. The chips produced with the smaller drills were continuous, undiscolored and flowed freely up the flutes of the drill while those produced by the one-inch drill were discontinuous and showed discoloration indicative of a higher temperature. The irregularity of the traces for the larger drill is due to the periodic formation and discard of a large built-up edge and the difficulty with which the chips moved in the flutes of this particular drill.

A dynamometer such as the one described can be useful in evaluating the influence of changes in drill design such as helix angle, shape of flute, point angle, clearance, chisel point angle and chisel point thickness, as well as the effects of changes in operating variables, cutting fluids and drill material. However, in interpreting data from a cutting dynamometer, it must be kept in mind that tool life is the chief item of importance, and it is necessary to conduct some life tests in order to establish a basis of evaluation of the cutting forces.

It is well-known that the life of a cutting tool is directly influenced by the temperature at which it is operated. Since practically all of the energy expended in a cutting operation is converted into heat, and the operating temperature at the point of a drill varies directly with the rate at which energy is dissipated it is evident that the power consumed in the drilling operation is of interest with regard to tool life. The total power consumed in a drilling operation is

$$P = P_o + P_f$$
$$= 2\pi T_o N + fNT, \text{ in-lb/min.}$$

where P_o is the power associated with the torque, in-lb/min

P_f is the power associated with the feed, in-lb/min

T_o is the mean torque on the drill, in.-lbs.

N is the speed of the drill, rpm

f is the feed, in per rev.

T is the thrust on the drill, lbs.

For the tests of Fig. 2 energy is expended at the following rates [see table] when equilibrium is established.

The total power consumed is seen to be divisible into two parts—that associated with the torque and the relatively small part associated with thrust. About half of the thrust power is expended in pushing the chisel point of the drill through the workpiece, while the torque power is generated at the cutting edge. Inasmuch as the torque power P_o is dissipated along the cutting edge, in contrast to the thrust power, the severity of the "thermal loading" along the cutting edge may be conveniently measured by the quantity P_o/L where L is the actual length of the cutting edge. Thus the quantity P_o/L represents the rate at which heat is generated at the cutting edge per unit length of cutting edge, and this quantity should be related to tool life in those cases where the failure is due to too high an operating temperature.

Values such as those in the foregoing table may be readily obtained by use of a tool dynamometer, and are helpful in surveying the importance of changes in design and operating variables. However, as already mentioned such tests must be supplemented by some life tests.

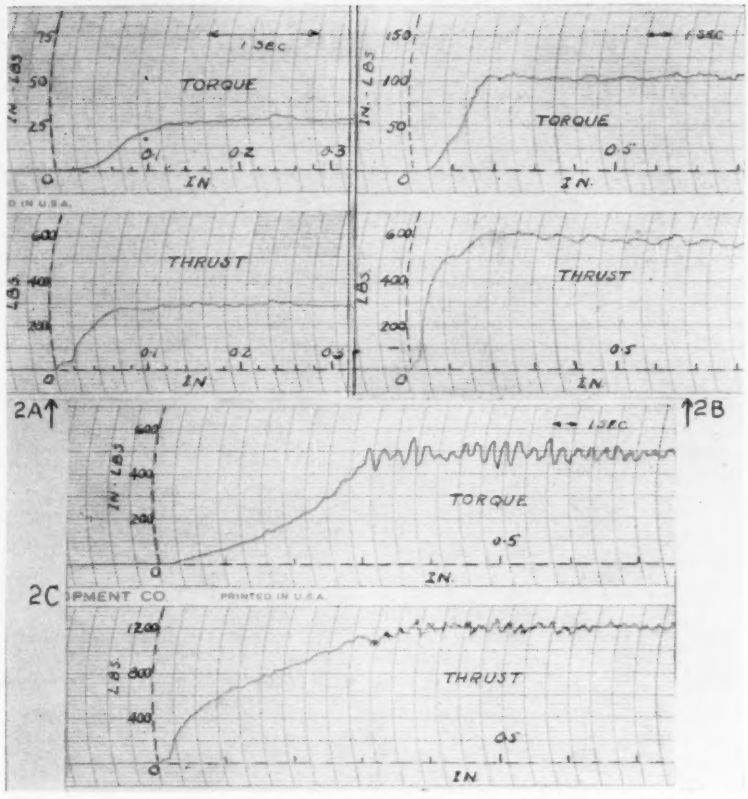


Fig. 2. Representative Data for AISI—B1112 Steel Drilled Dry.
(A) ¼ inch diameter drill, 800 rpm, 0.009 inch per revolution feed.
(B) ½ inch diameter drill, 360 rpm, 0.009 inch per revolution feed.
(C) 1 inch diameter drill, 215 rpm, 0.009 inch per revolution feed.

Drill dia., in.	Torque Power P_o, in-lb/min	Thrust Power Pf in-lb/min	Total Power/P, in-lb/min	BTU/min	Length of cutting edge L, in	Po/L BTU L in min
0.25	136,000	2020	138,000	23.0	0.28	52.3
0.50	238,000	1875	240,000	33.5	0.562	46.5
1.00	650,000	2320	652,000	79.2	1.125	62.0

A New Inductance Method *for* Remote Indication *of* Tank Level

By J. M. MARZOLF, Naval Research Laboratory, Washington 25, D. C.

A NEW type of remote liquid-level indicator has been developed at the Naval Research Laboratory for application to shipboard tanks where many factors, principally the roll and pitch of the ship, limit considerably the accuracy obtainable using available gages.

The ideal tank level indicating system for shipboard use should be simple, safe, dependable, practical and easy to install and maintain. No exposed electrical contacts should be used either inside the tank or in the vicinity of the tank. The system should provide accurate and dependable remote indication at several locations simultaneously and should hold its calibration for a long period of time. It should be applicable to all types of liquids and all tanks regardless of their size or shape. The indicator should be reasonably accurate under all conditions of roll and pitch of the ship and should not be affected by shock, vibration, or swirl of liquid in the tank. Variations in temperature, pressure, or the physical constants of the liquid in the tank (such as specific gravity, dielectric constant, purity) should not cause inaccurate readings. Furthermore, it would be desirable to provide some means of easily checking the operation of the indicator and adjusting its calibration without emptying or filling the tank.

In an effort to meet these rigorous specifications, one type of indicator tested in the laboratory consisted of a variable-wound coil, whose inductance varied linearly as a steel float passed through it. The Laboratory model is shown in Fig. 1.

The tank unit of this model consisted of a series of 48 one-inch coils wound with enameled wire on a non-conducting non-magnetic plastic tube and connected electrically in series. The number of turns on successive coils (starting with the smallest coil at the bottom) was so chosen that the squares of the number of turns of successive coils formed an arithmetic progression. Inside the plastic tube on which the coils were wound, there was placed a cylindrical steel float two inches long constructed of Type 4750 Allegheny Ludlum steel so that its diameter would fit loosely inside the plastic tube. The tank unit was enclosed in a steel shield (not shown in Fig. 1) which was slit on one side to reduce eddy currents. This entire unit was placed vertically in the tank.

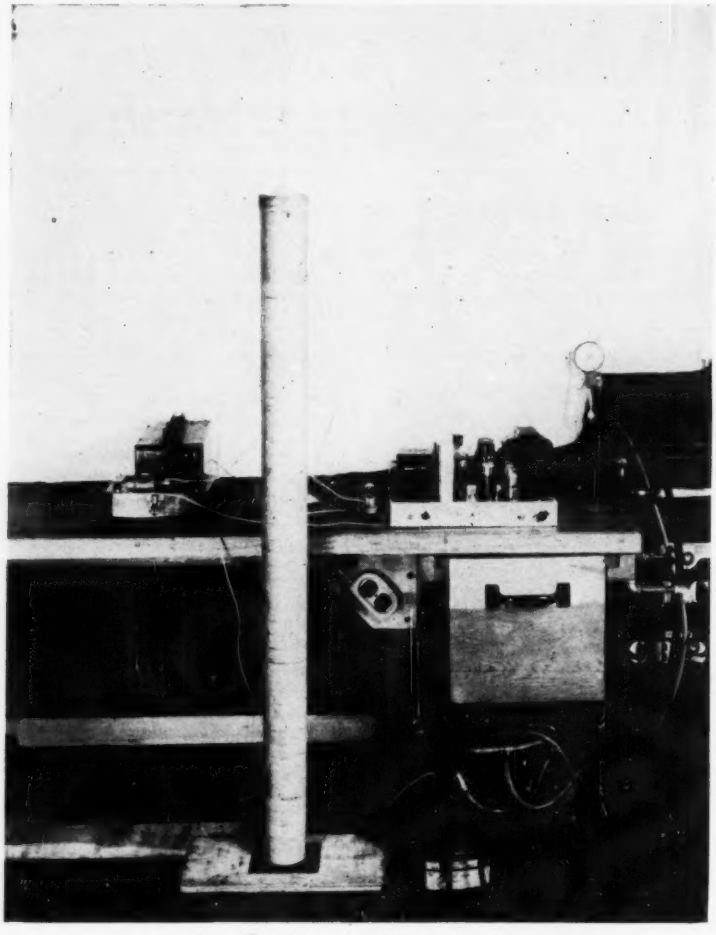


Fig. 1 Laboratory model of inductance-type tank level indicator.

Thus, as the steel float moved upward through successive coils, it had an ever-increasing effect on the total inductance of the circuit, since it moved into successive coils having an ever-increasing number of turns. Owing to the fact that the float spans several coils and also owing to the fringing of the leakage flux, the relation between inductance and float position varied continuously and linearly throughout its range.

The coils could be imbedded in a suitable material as a protection against the chemical action of liquids in the tank. Also, by limiting the number and size of the orifices in the bottom and top of the tank unit, the desired amount of fluid damping could be provided for stability under conditions of roll and pitch of the ship. The steel shield, in addition to providing desirable electrical properties, would also provide physical protection to the coils during installation and tank cleaning operations.

The development of a suitable measuring circuit for this type of gage was the most difficult part of the problem for the following reasons:

(1) The change in inductance produced by the float is relatively small compared to the total inductance of the circuit.

(2) The resistance component of the impedance of any coil is not negligible with respect to its reactance, and the resistance and reactance components cannot be easily distinguished from each other in an a-c. circuit, and

(3) The system must provide a continuous indication, without the necessity of balancing a bridge for each reading.

However, a suitable measuring cir-

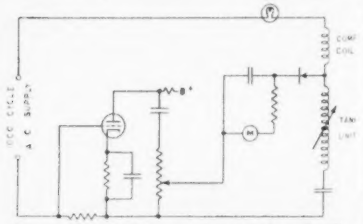


Fig. 2 Circuit diagram of measuring circuit.

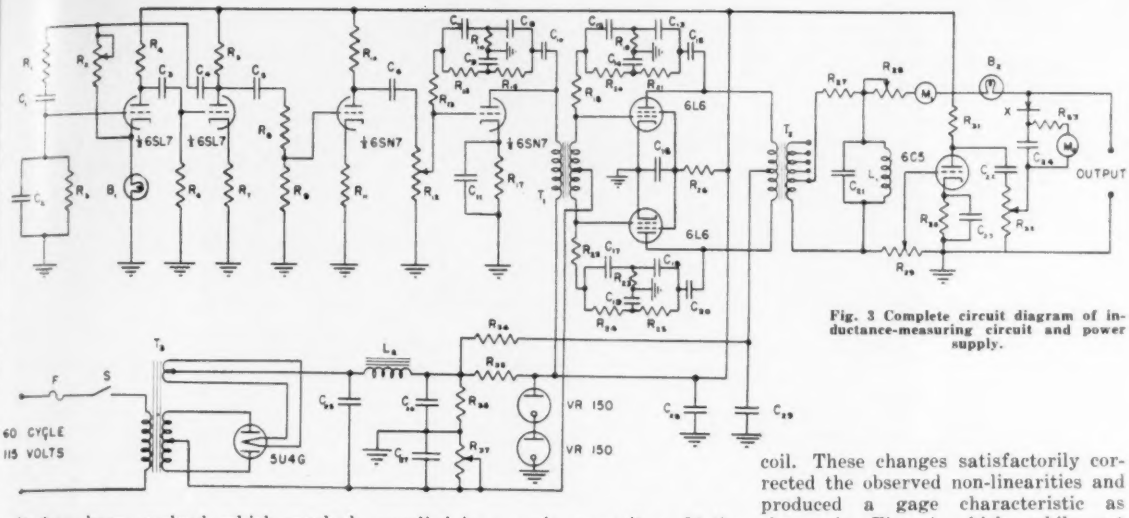
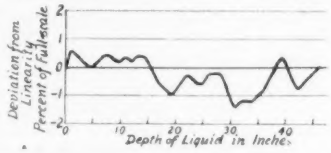


Fig. 3 Complete circuit diagram of inductance-measuring circuit and power supply.

cuit has been evolved which worked quite satisfactorily. It is shown in simplified form in Fig. 2. This circuit essentially provides a means of measuring the voltage drop across the tank unit while a current, constant in magnitude and frequency, is passed through it. At the same time two additional voltages are introduced into the measured portion of the circuit. One of these voltages is provided by the vacuum tube, whose output is equal in magnitude but 180 degrees out of phase with the *IR* drop in the tank unit. The other voltage is furnished by the series condenser, whose reactive drop is equal in magnitude but 180 degrees out of phase with the reactive drop of the tank unit, when the tank is empty. Thus, all the voltages in the measured circuit add vectorially to zero and the indicator will read zero when the tank is empty if the harmonics in the power supply are negligibly low. As the liquid level rises, the float changes the inductance in the measured circuit and the reading will be directly proportional to this change in inductance and hence to liquid level, provided that the current and frequency remain constant.

The vacuum tube serves as a voltage inverter. By taking its grid signal from the resistance in series with the tank unit, its signal will always be in phase with the current through the tank unit. Therefore, the plate signal produced across the shunt-fed load will be 180 degrees out of phase with the current through the tank unit if the blocking capacitor is large enough to produce only a negligible phase shift. The vacuum tube, therefore, fixes the proper phase relationship for the voltage introduced into the measuring circuit and the magnitude of this voltage can be adjusted initially, by means of the potentiometer tap, to the proper value to balance the *IR* drop in the tank unit. If the current is constant this voltage drop will remain constant throughout the range of the instrument.

The other voltage, which is required in the measuring circuit to balance the residual inductance of the tank unit when the tank is empty, can easily be supplied by a series capacitor. If the capacitor and tank unit are placed in series so that the current is the same through both, then the value of the capacitance can be so selected that the reactance drop of the capacitor will be equal in magnitude to the reactance drop of the tank unit when the tank is empty. Obviously, under these conditions, the reactance drop in the capacitor and tank unit will be equal in



magnitude but 180 degrees out of phase and they will cancel each other.

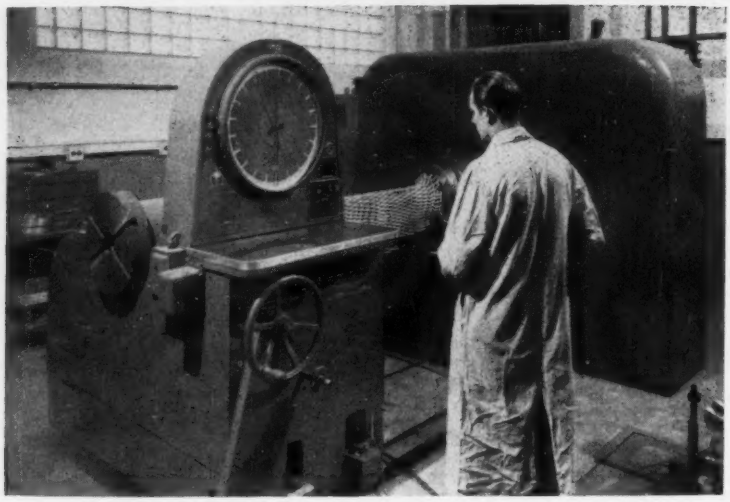
The indicating-instrument circuit must have a high impedance so that its current has a negligibly small effect on the circuits. Although a d'Arsonval-type instrument was used on these tests for simplicity and ruggedness, a vacuum-tube voltmeter would be preferred, because of its higher impedance and more linear characteristic. If several repeaters are desired of the d'Arsonval type, they can all be connected in series, with a corresponding change in multiplier resistance.

The power supply used was a Wien-bridge oscillator with a suitable amplifier equipped with bridged-tee networks to reduce the harmonics to an extremely low value. The Wien-bridge oscillator (1000 cycles) was selected because of its excellent frequency stability, and the ballast lamp shown in Fig. 2 provided a constant current output. The complete power supply and measuring circuit is shown in Fig. 3.

As originally constructed, this gage had a linear characteristic over the central portion but was non-linear at both ends because of the end effect of the coil and the non-linearity of the instrument rectifier. The float was allowed to move partially out of the lower coil and a compensating coil connected in the circuit as shown in Fig. 2 was wound over-laying the upper coil. These changes satisfactorily corrected the observed non-linearities and produced a gage characteristic as shown in Fig. 4 which, while not exactly linear, was considered quite satisfactory for purposes of this investigation. Should more precise linearity of performance be desired, it could easily be done by adding or subtracting a few turns from each individual coil at the proper locations.

This type of gage could be used in any tank containing a single liquid. It could also be used to measure the depth of the common surface between two immiscible liquids when stored simultaneously in the same tank if the float were designed with the proper specific gravity to remain at the interface. No exposed electrical contacts are used either inside or in the vicinity of the tank and there are no electrical or mechanical connections to the float, which is the only moving element in its construction. This gage will indicate the depth of the liquid in the tank independently of any changes in the physical constants of the liquid. If properly designed and installed, it should be relatively free from maintenance troubles and is so constructed that fluid damping can be easily provided to minimize errors produced by tank movement or swirl of liquid in the tank. By providing a suitable switch to substitute for the tank unit a dummy inductor having the same inductance and resistance as the tank unit, the operation of the gage can be checked and adjusted without emptying or filling the tank.

This gage operates on a distinctive principle and was designed particularly for shipboard operation. However, it might be applicable to other installations either in the manner described or with certain modifications. For example, by properly designing the number of turns on the coils of the tank unit, a linear scale could be obtained on the indicator for an odd-shaped tank; increased sensitivity could be provided over a limited range; or localized coils could provide the actuating signal for automatic liquid-level control systems or alarm circuits. Other variations might be made on this basic principle for specific applications.



A 1,000,000-in. lb. Baldwin torsion machine is used by Mack Trucks, Inc., in its research laboratory at Plainfield, N. J. to test axle shafts, crankshafts, frame and body members of buses and trucks. Specimens are wrapped with burlap and covered with a blasting mat. The face plate at left is used to calibrate an adjoining torsional fatigue machine. Motor control buttons on the end of an extension cable permit the operator to control tests at any convenient position. Loads are weighed by an Emery cell and transmitted to a Tate-Emery indicator.

The Use *of the* Torsion Test

By F. G. TATNALL, Manager of Testing Research, The Baldwin Locomotive Works, Philadelphia

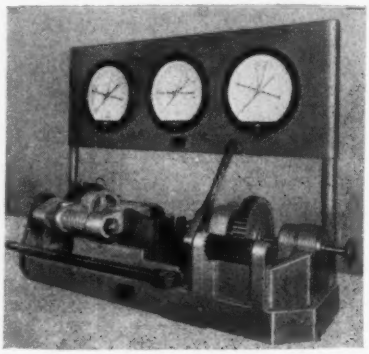
APPRECIATION of the torsion-test in the evaluation of materials is growing among those who have been using the test to some extent, and the test is also being utilized more widely. There are several conditions under which the torsion test is advantageous other than in testing parts, such as axles and shafts, in the manner in which they are to be used. It tests materials in direct shear; it is a test for brittle materials, a sensitive test for surface corrosion, and it has been used as an accelerated creep test.[1]

One important characteristic of the torsion test is that it progresses from beginning to end without instability. In other words there is no appreciable change in size of the specimen when tested in the plastic range to fracture, except for a slight shortening. For this reason the test is stable in the plastic range. Instability occurs only when a decreasing cross-section must carry an increasing load, as in the necking down of a tensile test or in the bursting test of a cylinder.

The torsion test is not good for determining elastic limit because the transition from elastic to plastic range is progressive, i.e. the outside fibers, which are subjected to the greatest stress, yield first while inner fibers are still elastic. As the test continues the fibers nearer and nearer the axis yield progressively. There can be no upper and lower yield point or "drop of beam."

The fact that torsion applies maximum stress at the surface is important in making the test sensitive to surface corrosion. For the same reason brittle materials such as tool steels and cast iron or case-hardened materials can be evaluated by the torsion test because of the stress gradient from surface to core which takes advantage of the supporting action of the under-stressed core.[2,3]

Since internal material has little effect on torsion test results and shearing stress varies with distance from the axis, hollow members or thin-walled tubes are preferred in determining values of shear stress. However, if the wall is too thin for stability, compressive forces will exceed shear and the tube will collapse.



This special machine was designed for Holo-Krome Screw Corp. to test hollow-head cap and set screws in tension and in torsion. Loads are measured by two Emery cells which transmit hydraulic pressures to Tate-Emery indicators. The machine applies up to 75,000 lb. in tension and up to 10,000 in. lb. in torsion.

Although torsion test specimens are usually cylindrical, no standard dimensions have been established. Full-size parts are frequently tested. Finished machine parts ready for assembly are commonly tested by applying the torsional loads encountered in service. The greater the length of test section the more marked the yield point on a torque-twist graph.

In torsion tests, shear is defined as the resistance to rotation or lateral displacement. Shear occurs in the plane of twisting, normal to the specimen axis. The material is stressed in tension and compression at 45 deg. to the shear plane and, to maintain equilibrium, there must be a component of longitudinal shear. Shear and axial stresses maintain this 45-deg. disposition in all stress patterns.

Shear stress computations are determined from the force (P) in pounds at the end of a lever arm p in. long, and the diameter (d) of the test bar or the external and internal diameters (d_1 *and* d_2) of a tubular specimen.

For solid bars,

$$S = 16\,Pp/\pi d^3 \qquad \text{(a)}$$

For tubes,

$$S = 16\,Ppd_1/\pi(d_1{}^4 - d_2{}^4) \qquad \text{(b)}$$

The torsional strength of solid bars averages roughly about 68 percent of the true tensile strength. By true tensile strength is meant the stress based on the reduced section of the tensile bar. The value for a typical cast iron is 30,000 psi. and for a common steel is 65,000 psi.

The shearing modulus of elasticity

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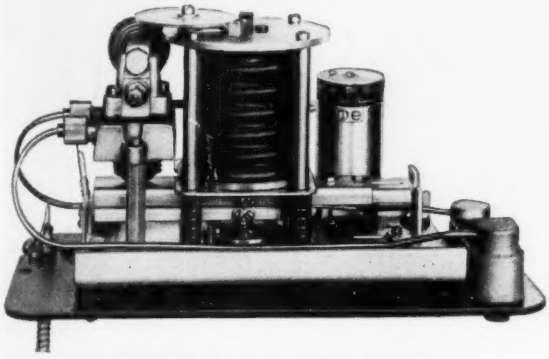

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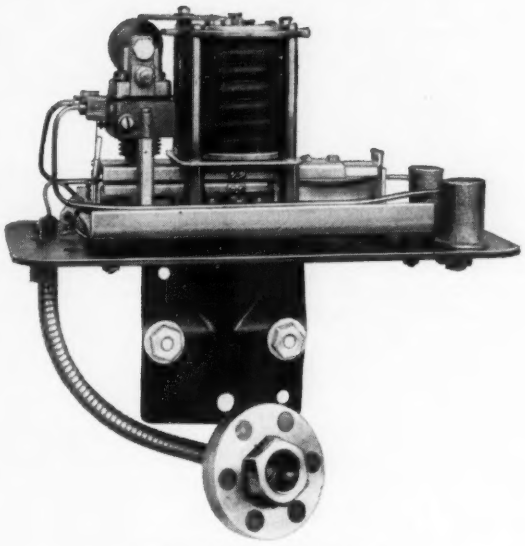

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(F) or "modulus of rigidity" is approximately 6,000,000 psi. for a typical cast iron and 12,000,000 psi. for ordinary steel. These values are derived from the formula:

$$F = Ppl/JA$$

where l is length of stressed section, J is polar moment of inertia, and A is angle in radians through which the specimen is twisted.

The unit stress at fracture in torsion is frequently computed from formulas (a) and (b). This value is called "modulus of rupture" but is fictitious because the formula is based on the proportionality of stress to strain which is not valid above the elastic limit.

The fact that the modulus of elasticity in shear is so much less than in tension simplifies the mechanical recording to the load-deformation diagram. This is because tensile strains have to be magnified by an elaborate extensometer to produce a readable curve, whereas twist can be measured by means of a simple device. The greater elastic deformations for given loads in torsion account for the fact that brittle materials can be tested in this manner so satisfactorily.

The area under the torque-twist curve, plotted to rupture, represents the absorbed energy or the toughness of material. The static torsion test evaluates toughness qualitatively as well as quantitatively. For example, the curve reveals whether toughness is derived from high strength and low ductility or from low strength and high ductility. On the other hand the torsion impact test gives one value for toughness representing quantitatively only the area under the torque-twist curve.

Shear strength is not always lower than tensile strength, as required in a ductile material. When shear strength exceeds tensile strength, shear failure becomes a shatter failure at 45 deg. to the axis instead of normal to the axis. This condition commonly occurs in hard steels in which there are residual quenching strains.

Theoretically a homogeneous material should never fracture in a torsion test. However, residual strains, internal notches, flaws and imperfections interfere with perfect slip action and set up incipient cracks that lead to failure.

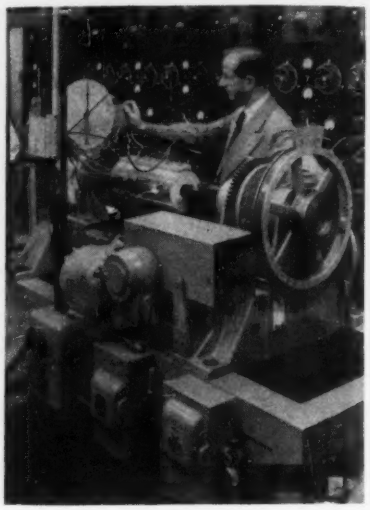
The torsion test is of particular significance in that part of the torque-twist diagram lying beyond the elastic region. Its use in determining a value for the ultimate strength of a cylinder subjected to internal pressure has proved to be valid for the design of pressure vessels.[4]

Torson tests can be performed more conveniently than many other types of tests at elevated temperatures because the furnace can be mounted easily so as to eliminate the gripping and extensometer problem. Constant load tests are especially easy to conduct by the method suggested by Sauveur.[5]

Torsion Testing Machines

Improvements have been made recently in both the weighing head and twisting head of the torsion testing machine. Modern weighing heads may employ mechanical, hydraulic or electrical methods of weighing the torsional load. Improved pendulum balances now permit the use of a self-indicating dial, graduated directly in inch-pounds and capable of driving a stylus to plot the "torque" ordinate on a recorder.

Hydraulic weighing is accomplished by a torque arm bearing on the weighing head which is supported at its outer end on a packless hydraulic cylinder or on an Emery type hydraulic capsule like those commonly used on modern



Torsion tests are made at high temperatures in the laboratory of the M. W. Kellogg Co., using a Baldwin testing machine.

hydraulic tension testing machines. Hydraulic systems are self-indicating on large dials in selective ranges and can drive a recorder stylus to plot the "torque" ordinate.

The electric method takes advantage of the fact that, in torsion, tension and compression components of force are at 45 deg. Resistance wire strain gages are mounted in these directions on a shaft that is arranged to resist the torque. The torque unbalances a Wheatstone bridge circuit in which the gages are connected, thus operating a servomotor-driven self-balancing bridge indicator and recorder.

The driving end has been improved by a new type of electronically controlled motor. Drive units of this type can be connected to ordinary 60-cycle 110-120-volt a-c. circuits. These units give a wide range of speeds up to 100 to 1 with stepless variation and constant torque at the drive shaft. Since testing speeds required in torsion tests vary from less than 1 deg. per minute to more than 360 deg. per minute, one gear change in combination with this variable speed motor gives exceptional flexibility in the drive.

A large variety of gripping arrangements are required because there are no standards for specimens. Common types of grips include:

1. Self-tightening hinged sectors with serrated faces. These are not proof against "slipping in the grips" and are suitable for twisting in only one direction.

2. Universal chuck type for small loads.

3. Expanding collets for use with hollow specimens apply torque in either direction.

4. For positive non-slip gripping in either direction of twist, square or form-fitting dies that fit square or special shaped ends of specimens are preferred. Specimens for these grips are limited in size and shape and their ends must be either cast or machined.

5. Face plates are one of the simplest and most flexible methods applied except that the cost of preparing a specimen with matching flanges, face plates or bolting members must be considered and set-up time may exceed that of other methods. This method accommodates a variety of shapes and sizes of specimens and is suitable for reverse twisting.

The purpose of reverse twisting may be for plotting the stress cycle in the form of hysteresis loops, or for alternating torsion such as a torsional vibration or for determining damping properties.

Torque-Twist Recorder.—All of the weighing methods that have been described are capable of driving either a recorder drum or the stylus to plot the torque coordinate. The twist coordinate is usually plotted autographically in either of two ways. One is a direct drive by flexible shaft from the twisting head of the machine. When this method is used grip slippage cannot be permitted. The second method is by troptometer or torsional deformation meter, which measures angular distortion of the specimen on a fixed gage length. This device must be carried by the specimen. The method of attachment must not damage the specimen surface by indentation which might concentrate stress in the most highly stressed fiber. A troptometer may be mechanical or electrical. Its strain magnifying power need not be as high as in extensometers for tension tests.

Troptometers are not in common use and not many satisfactory instruments have been devised. However, new electrical methods have given satisfactory results even with torsional deformations up to 360 degrees.

Further data on torsion testing are given in the American Society for Metals publication by H. D. Churchill on "Physical Testing of Metals and Interpretation of Test Results."

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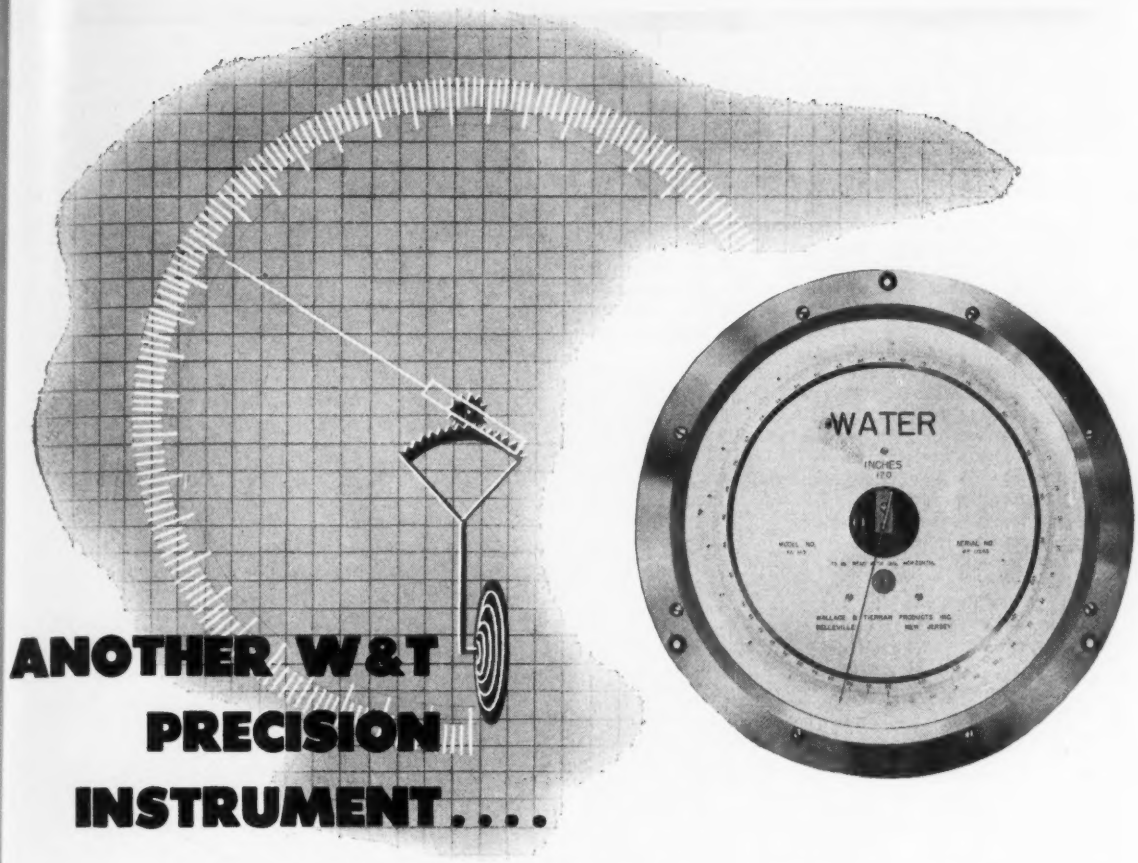

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INSTRUMENTS ON THE MARCH

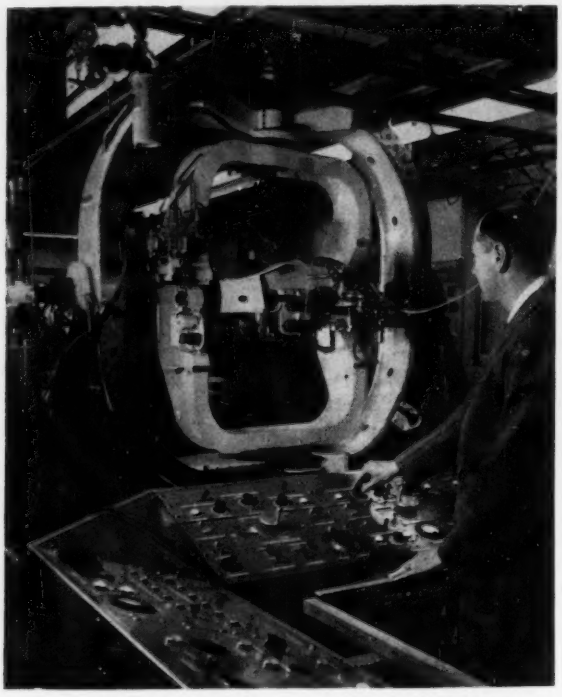
Aircraft and Flight-control-system Analog

LOS ANGELES, Calif.—A new instrument designed to check flight characteristics and control equipment of an aircraft prior to its construction was announced here by Dr. James R. Killian, Jr., president of the Massachusetts Institute of Technology, in an address to MIT alumni outlining the Institute's current $20,000,000 mid-century program of expansion.

On this elaborate and sensitive calculator, known as the Flight Simulator, MIT engineers will be able to set up an electrical model of any aircraft which is in an advanced stage of design and then apply an actual autopilot to fly this non-existent, theoretical craft.

The autopilot, which may be the "muscle" of either a guiding mechanism for a guided missile or an automatic pilot for a more conventional airplane, then has exactly the same problem that it would have in the actual flight of the missile or airplane, were the prototype built. Thus the simulator is able to "flight-test" an aircraft in the design stage.

A combination of electronic and mechanical equipment, the flight simulator represents the results of a cooperative



The flight simulator at MIT is operated from this control panel, at which stands Dr. Albert C. Hall, Director of the MIT Dynamic Analysis and Control Laboratory. The gimbal frame responds to the various commands given from this board to the theoretical aircraft.

project involving more than fifty engineers and nearly three years' work. It was built under the auspices of the U. S. Navy Bureau of Ordnance in the MIT Dynamic Analysis and Control Laboratory, of which Dr. Albert C. Hall, associate professor of electrical engineering, is director.

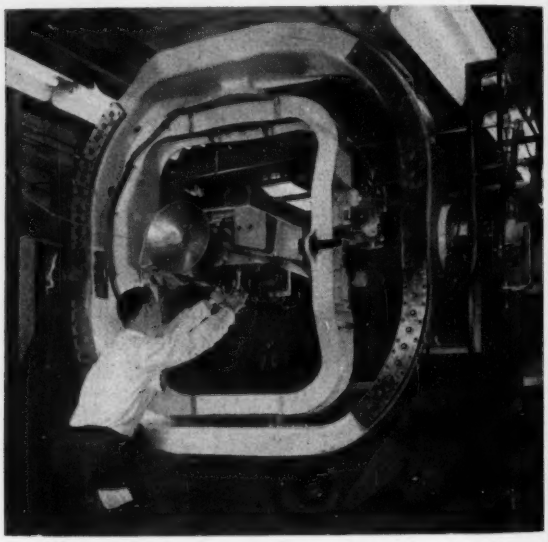
Because it enables engineers to study some of the flight characteristics of any given design before construction is begun, the simulator can save much of the cost and time of flight testing and should help in improving aircraft design. It requires only flight characteristics obtained from working plans and measured data from wind-tunnel tests of a model of the proposed craft.

If, for instance, aircraft performance on the flight simulator is not satisfactory, the wing and tail designs of the electrical model may be changed by simple adjustments of the simulator controls until the desired behavior is obtained. Suitable changes can then be incorporated in the plans before the actual plane is built.

Thus, in an age when planes are called upon to fly faster and further, this instrument is expected to save valuable development time by making available prior to construction much information hitherto obtained through flights.

"The fundamental purpose of this machine" Dr. Hall explains, is to permit the development of high-speed aircraft with a reduction in the time, expense, and number of conventional flight tests."

The flight simulator involves the use of intricate computing machines and a flight table on which actual problems relating to flight stability are worked out. The table is an arrangement of gimbals, delicately suspended so that they can incline freely in any direction and supported on an independent foundation so that there will be no vibration. The gimbal frame, operated by high-speed hydraulic servomechanisms which carry out motions in accordance with electrically-transmitted commands, is used to orient the automatic control system of a plane or missile just as it would be tested in actual flight. The gimbal frame table rolls, pitches, and goes through all the motions the plane would make in the air under stated conditions. This, of course, is where the simulator gets its name. It is designed to simulate those exact conditions under which an aircraft can operate.



Heart of the flight simulator is this gimbal flight table which moves in the same way as would the aircraft under study. Here Ralph E. Kimball, executive officer of the MIT DAC Lab, is adjusting the flight table control mechanisms. Above his head is a radar antenna which is part of the theoretical aircraft's automatic-control equipment.

Although the motions of the gimbal frame table, and thus the actions of the hypothetical plane or rocket in flight, are recorded on charts, the visual study of the gyrations is of highest consequence, too. This is an important way of gaining information, and those visual findings of the engineer can later be checked with the mathematical record.

A problem is worked out on the apparatus by setting electronic computer dials that represent the various important characteristics of the aircraft to be studied—weight, velocity, altitude, wing span and many others. Before the simulator can be used, many of these characteristics must be obtained from wind-tunnel tests of small models of the proposed aircraft.

Then the question is fed into the simulator by applying appropriate electrical signals through a control board. The

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(Model B-1169 WM)

Semi-steel clean-out head is removable from body frame for filling and cleaning U-tube. For line pressures up to 100 lbs. per sq. in. Large bore "pyrex" tubing 3/16" inside diameter gives flat indicating fluid meniscus. Bold ½" high scale numerals provide for distant reading. Ask for catalog sheet B-1169 WM.

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For portable service in the field, production testing, or in the laboratory. Glass tubing is gland packed at each end block and is supported at spaced intervals to prevent tube distortion. Also available for wall mounting, pipe mounting, and flush front panel mounting. Ask for catalog sheet A-203 TM.

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The instrument body channel, scale, and indicating tube mount to the front of the panel; instrument well mounts behind panel. Connections are made behind the mounting panel. Provides an accurate, quick, and direct method of measurement. Ask for catalog sheet A-324 FB.

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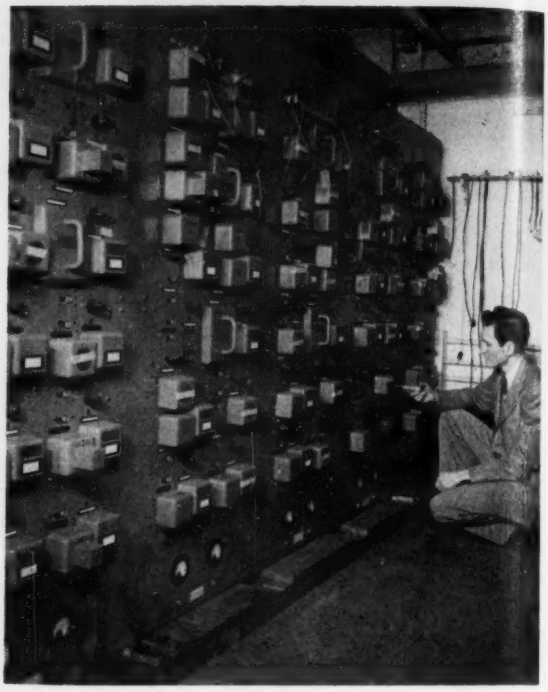


In this computer of the flight simulator, engineers set up characteristics of an aircraft whose flight performance is to be checked. The computer contains electronic elements for adding, multiplying, and integrating.

answer is returned on a chart on a recording apparatus in a matter of seconds.

This computer, one of several types of such high-speed mathematical machines at MIT, adds, multiplies, integrates and subtracts at almost unbelievable speed. For example, a computation which would take an able operator a hundred hours to carry out by hand is handled by the computer in ten seconds, and much more elaborate problems can also be handled in a matter of only minutes.

Among MIT scientists contributing to the result were Dr. John F. Blackburn, development of automatic controls and supervision of the mechanical design of the gimbal frame; Emery St. George, Jr., development of instruments and electronic components; Charles M. Edwards, design and development of the electrical computer; and Thomas F. Jones, Jr., in charge of simulator operation. The detail design of the gimbal frame was carried out by a group supplied by the firm of Jackson & Moreland, consulting engineers, and the gimbal frame was manufactured by a group of companies in the Detroit area, each a specialist in its field.

Three-dimensional Photoelastic Stress Analysis

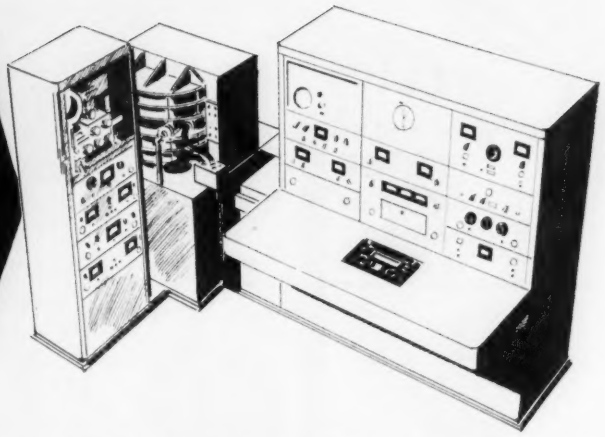
CHICAGO—A $4,000 research grant has been awarded to Dr. Max M. Frocht, research professor of mechanics at Illinois Institute of Technology, by the Research Corporation, New York, for fundamental study in three-dimensional photoelastic stress analysis.

Until recently, photoelasticity has been confined mainly to two dimensions, the stress in depth assumed to be constant. In three-dimensional work, studies have been limited to symetrical objects. Dr. Frocht's work will be to extend the scope of photoelasticity to general problems and to improve the method for symetrical problems. It will include a study of fundamental principles, perfecting methods and techniques, and an application to practical problems.

Photoelasticity is an experimental method of determining stress by applying loads to transparent models of real objects in a polariscope and analyzing quantitatively the pattern produced by the interaction of the polarized light with the model.

New . . . Improved

ANALYTICAL MASS SPECTROMETER



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The new Model 21-103 Analytical Mass Spectrometer, representing nearly three years of additional intensive research and development, retains the qualities and advantages of its predecessors—the Models 21-101 and 21-102—but provides still greater flexibility, sensitivity, accuracy, range, and overall usefulness.

This new mass spectrometer has been engineered to meet more fully the needs of the chemical industry. Its features, including the new ion source, the ISATRON, greatly enhance the use of mass spectrometry for purity determinations, and quantitative and qualitative analyses of mixtures of all types of gaseous and liquid compounds, including hydrocarbons, inorganic gases, and oxygenated and other substituted organic derivatives. For further information, write Dept. MS-3.

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We will be glad to send you a sample of our standard ¼" tape on either plastic or paper base. And if you have a specific application in mind, please write, outlining your requirements.

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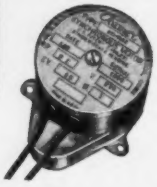

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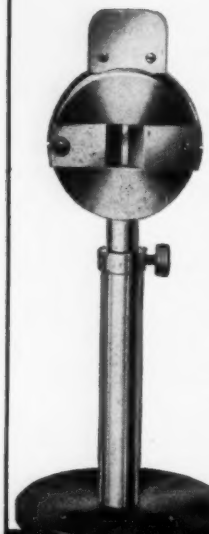
Thermopiles



For many years the thermopile has been the accepted instrument for measuring Radiant Heat from Radiant Heaters at the American Gas Association Testing Laboratory in Cleveland, Ohio. Since 1930, when Vandaveer first described his work in this field,* an Eppley thermopile has been used for this purpose in hundreds of tests and the results have been consistent and accurate to within 1 per cent.

This is but one of many applications in the field of radiant energy measurements for which Eppley Thermopiles are ideally suited. They may be obtained with windows of different materials, and various types of black are available for receiver coatings.

All Eppley Thermopiles are supplied with a certificate of calibration, this calibration being made against a Standard Lamp from the National Bureau of Standards.

If you have a problem involving the measurement of radiant energy we invite you to write us, describing your problem in as much detail as possible. We will be glad to make recommendations and there will be no obligation.

*Vandaveer, *Industrial & Engineering Chemistry*, Vol. 22, page 596, June 1930.

BULLETIN No. 3 ON REQUEST

THE EPPLEY LABORATORY, INC.

SCIENTIFIC INSTRUMENTS

NEWPORT, RHODE ISLAND, U. S. A.

"More Power to America" Exhibit Train Features Instruments

NEW YORK CITY.—The General Electric Company today unveiled its More Power to America Special, the biggest electrical display kit ever built. Almost a quarter-mile long, the 10-car exhibit train represents the first attempt to display, in one series of related exhibits, the complete range of products for the production, distribution, and industrial utilization of electric power. Believed to be unique in industrial marketing history, the silver streamliner is filled with exhibits of more than 2000 modern electric products, systems and techniques.

More than 250 different precise instruments designed to perform scores of valuable services throughout industry,

N. M. DuChemin, assistant general manager of G-E's Apparatus Department, looks over a display of watthour meters in the Measurements section of the More Power to America Special.

aboard ships, trains, and aircraft, and in laboratories and research centers are arrayed in the Special. Most of these are exhibited in the Measurements Section which emphasizes the importance of accurate measurement in every phase of industrial activity.

A series of related exhibits occupying two-thirds of a car shows the multitude of ways instruments—and combinations of instruments—can be appled to achieve dollar savings for the user. The latest instruments are shown, many of them in operating exhibits.

Potential-gradient Meter May Have Effect on Corona and Radio Influence

NEW YORK CITY.—A new instrument, developed to study the voltage gradient at the earth's surface, was announced by its inventors, R. L. Tremaine and R. C. Cheek of the Westinghouse Electric Corp., East Pittsburgh, Pa., before the American Institute of Electrical Engineers, "in the belief that a description of the instrument will be of value to other investigators." Their studies of the effect of the earth's voltage gradient on corona and radio influence, which are being conducted at the Tidd 500-kv. test lines at Brilliant, Ohio, have not yet been completed and will be reported on later. They described their instrument as a generator type gradient meter which has a continuously-rotating member, and which includes "a number of features which have not been available in any such instrument previously described in the literature."

Spectrophotometry

WASHINGTON, D. C.—Reliable spectrophotometric data should now be more easily obtained with the aid of a new booklet, *Spectrophotometry*, recently issued by the National Bureau of Standards and made available from the U. S. Government Printing Office. The techniques and data resulting from the Bureau's extensive experience in

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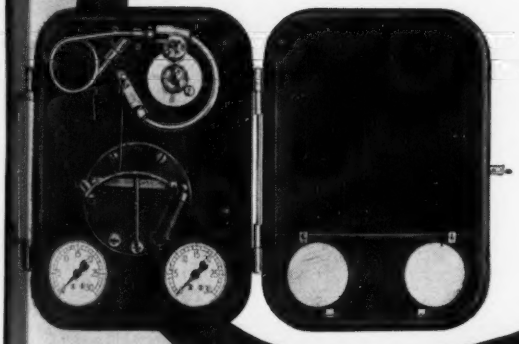
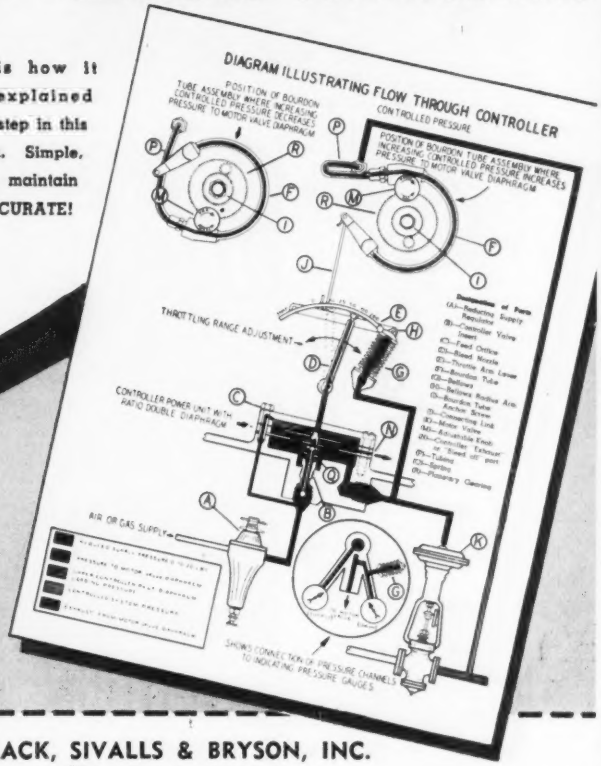
Type 1400 handles both positive and negative pressures, from high vacuum to 10,000 psi. It is adaptable to services requiring high sensitivity or to wide throttling ranges for dampening sensitivity. Overcomes hunting action which makes lined out pressure control difficult. Adjustable in the field for snap action. Bourdon-tube actuated.

BS&B *Climax* **TYPE 1400 PRESSURE CONTROLLERS**



Here is how it works, explained step-by-step in this diagram. Simple, easy to maintain and ACCURATE!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Now you can be assured positive and sensitive response to pressure changes, with a controller characteristic usually obtained only in more expensive type recording instruments. Climax builds it right, for long service under all conditions. A multitude of special adaptations are possible... Ask your BS&B-Climax Man today!

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His sound backlog of experience in process controls is available for your own use. He will be pleased to help you beat a tough problem. He is readily available, just check the coupon. Naturally, all inquiries are held in strictest confidence.

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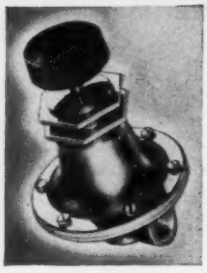

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It's built especially for dead end (no flow) service . . . and guaranteed to be free from "drift" errors. Ranges 0-5; 0-25; 0-50; 0-125 psi for inlet pressures to 150 psi.

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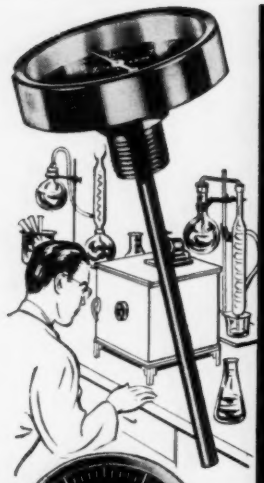

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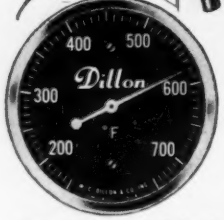

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spectrophotometry are presented in this guide so that users of spectrophotometer can better understand their instruments, calibrate and maintain them in the proper operating condition, and guard against the numerous errors common in such work. Instruments and methods for use in the ultraviolet, visible, and near-infrared spectral regions are considered, including photographic, visual, and photoelectric methods. Circular 484, *Spectrophotometry*, by K. S. Gibson, 48 large double-column pages, illustrated, available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 25 cents a copy. Remittances from foreign countries must be in United States exchange and must include an additional sum of one-third the publication price to cover costs of mailing.

New Method for Chromium Determination

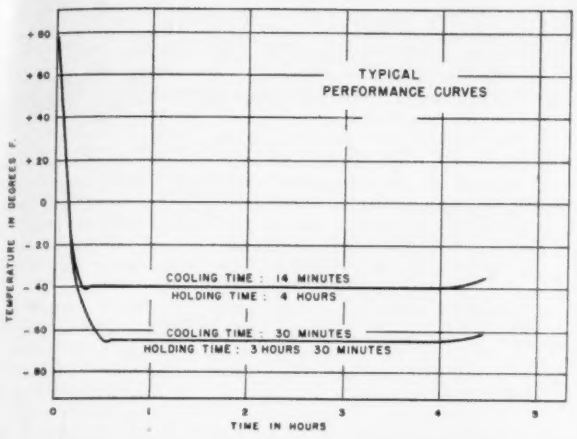
PITTSBURGH, Penna.—A new photometric method for the determination of chromium in 18-8 and similar steels is announced by scientists in the Development Laboratory of the Fisher Scientific Co. The method's speed is derived from the technique of simply dissolving the steel and measuring the absorption directly, using the Fisher Electrophotometer. Nickel, the only interferring element, need not be chemically isolated since the judicial choice of a narrow band filter renders the interference negligible. National Bureau of Standard steels were determined with a standard deviation of plus or minus 0.15 percent. The optimum range extends from 7 to 25 percent. Copies of a technical paper on the method, by R. M. Vredenburg and E. A. Sackter (which describe the theoretical aspects as well as a detailed procedure) are obtainable from the authors by addressing requests to Fisher Scientific Co., 717 Forbes Street, Pittsburgh 19, Penna.

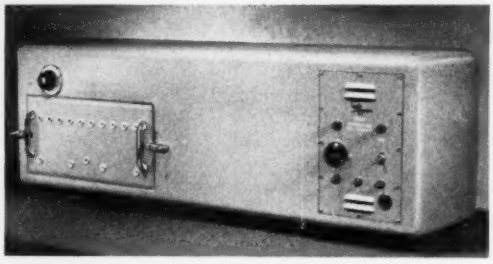
Invisible Oil-film Measured

PITTSBURGH, Penna.—An infinitesimal part of a single drop of pure vegetable oil, spread out in an invisible, molecule-high film, is pushed along the surface of distilled water like a log-raft. Then it is squeezed to rectangular shape so it can be measured conveniently by research technicians of Carnegie-Illinois Steel Corporation here. This delicate operation is performed in a new test to compute accurately how much oil clings to a big sheet of tin plate.

Either cottonseed or palm oil is applied to tin plate to help protect from rust and preserve the mirrorlike sheen of the American housewife's cans of food. So little oil is used it is rather a smooth "feel" of oil than a quantity. In addi-

Hydrophil balance in the Research Laboratory of Carnegie-Illinois Steel Corp. This and other subsidiaries of US Steel apply so little oil to can material that an ounce of it would cover all four walls, ceiling and floor of a hall of gleaming tin plate 50 feet wide, 20 feet high and 400 feet long.





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The Statham Model TC-1 Temperature Test Chamber is a compact, economical, and convenient temperature-controlled chamber for the rapid performance of ambient temperature variation tests. Thermostat control, balancing heat against dry ice evaporation, permits any temperature between —65° and +275°F to be maintained.

Completely portable, the Model TC-1 Temperature Test Chamber, which accepts a load volume of 600 cubic inches, is ideally suited to the performance of ambient temperature tests on basic instruments, electronic sub-assemblies, components, organic materials, small equipment, etc.

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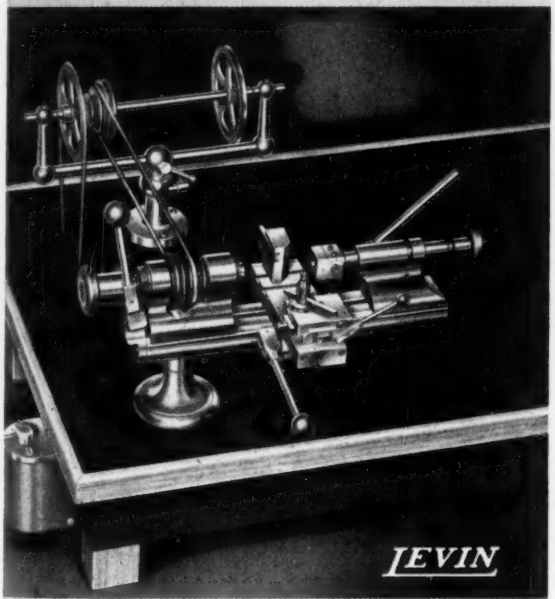

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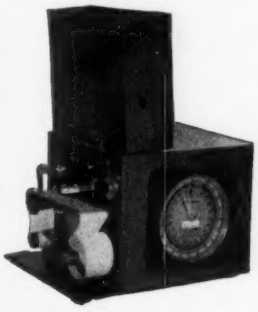

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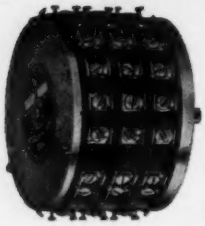

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Fairchild Type 748
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Here's a custom-built instrument that's typical of Fairchild's job-engineered solutions of difficult potentiometer problems. It's a 3-gang potentiometer with 17 taps per unit, giving 16 sections of equal resistance — 8 each side of center. By using resistors of various sizes between taps, almost an infinite number of non-linear functions can be approximated. For control purposes, each unit can be used as a continuously varying switch to fire tubes such as Thyratrons in sequence.

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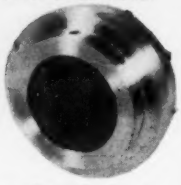

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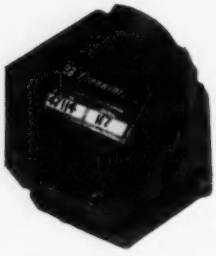

Absolute, gage, or differential pressures of corrosive fluids or gases.

There's a design now for any pressure range to meet your specifications and to withstand rigid vibration, temperature and accuracy requirements *with*

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Pressure ranges — from 1 psi differential to 6000 psi, gage or absolute.

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GM Giannini & CO INC

tion, the little bit of oil (a) facilitates the handling of sheets after they have been plated with pure tin and must go through rigid inspections for flaws before delivery to the can manufacturer. (b) It helps the makers of cans handle this thin-rolled material as it is cut into strips for can bodies and cut and stamped into round tops and bottoms, ready for assembly and soldering. (c) The minute film also causes lithographing ink, sometimes used for labeling, to flow more smoothly on tin plate.

The Carnegie-Illinois Research Laboratory's hydrophil balance oil test apparatus is basically a long, narrow tray, filled to over-flowing with clean distilled water. Crosswise of the tray are set two strips that dip slightly below the surface of the water and project a little above it. One of these strips is semi-fixed and the other is movable along a track to which is attached a graduated linear scale. The sample of tin plate whose oil film is to be measured—a small sample of exact test size—is dipped about five times vertically in the water to insure that the ionic action of the water will collect the oil on its surface. Like oil on water in all cases, this microscopic quantity spreads in an irregular layer of oil molecules. The movable tranverse strip is then brought slowly down its track the length of the tray, pushing ahead of it the film of oil until the pointer of the hydrophil balance deflects measurably. Deflection of the pointer means that the film of oil, invisible to the eye of the operator, has been compressed to a rectangle exactly one molecule thick and that the rectangle is pressing squarely against the semi-fixed strip. The area of the rectangular space, so delicately adjusted, is computed exactly. From this it is a simple matter to determine the weight of the oil film.

Radiography Technique Speeds Ship Sailing

NEW YORK CITY.—When steam boilers or pressure-carrying steam piping aboard a ship are repaired, replaced or modified by welding, it is necessary to satisfy the responsible and governing inspectors as to the satisfactory nature of the welds made. They must be free of cracks, excessive holes or slag inclusions and must represent good fusion of the base metal. The customary method of inspection is that of gamma-ray or radium radiography.

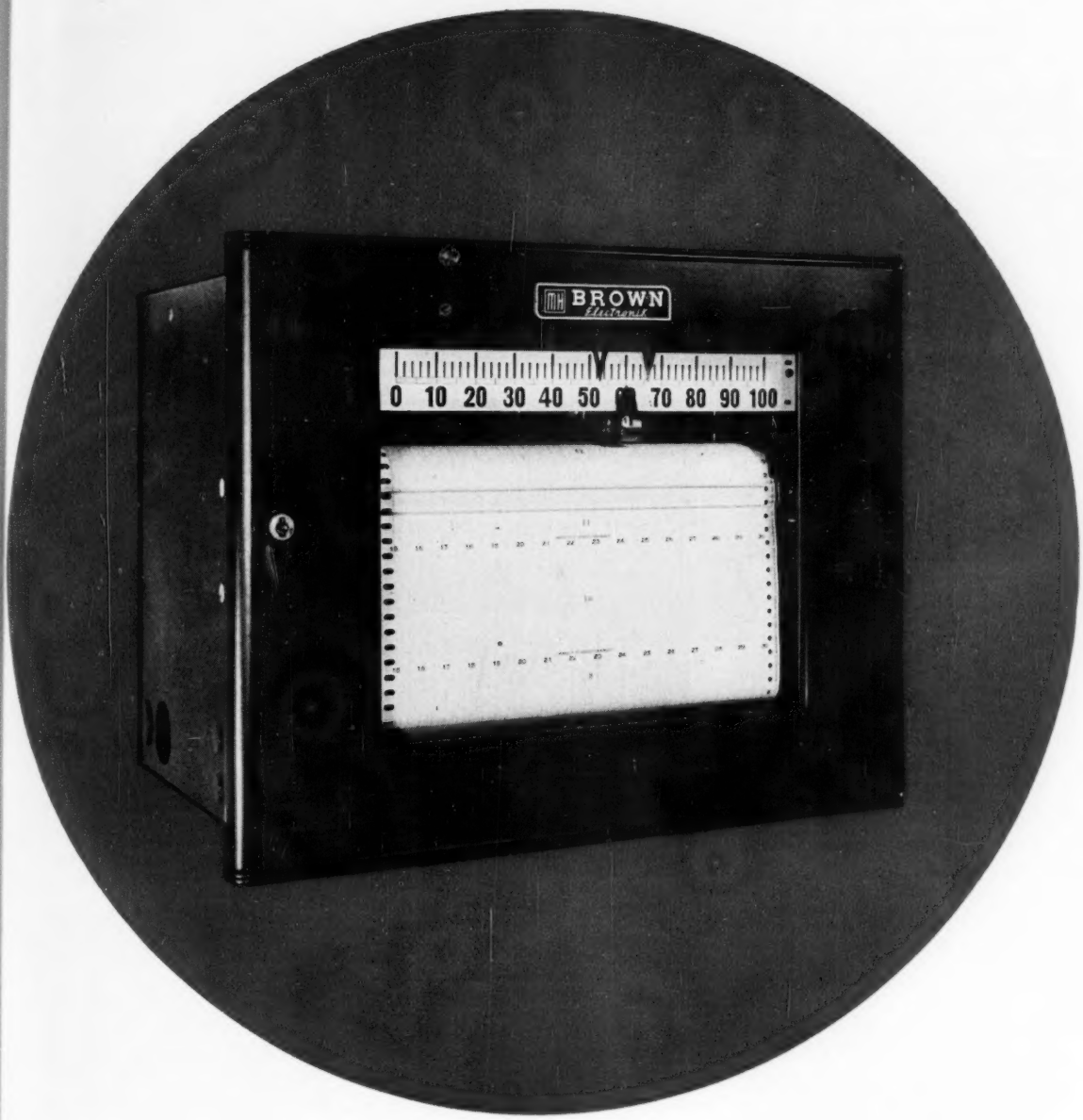
Gamma-ray radiography required a suitable source of the rays, such as radium or other radioactive material; methods for suspending this source in a proper position on one side but at some distance from the weld; suitable film in special cassettes with special intensifying screens; methods of holding these cassettes is position on the other side but close to the weld; suitable penetrometers to prove the sensitivity of the procedure; a calculated time for the exposure; suitable dark-room facilities for loading and unloading cassettes and developing the film; and know-how.

The entire procedure may take considerable time. An example was in a recent ship case where certain nozzle additions were made to the current boilers. Radium radiography of the welds by conventional methods required for each nozzle several hours for set-up time, some 14 hours of radium exposure and in addition several hours for processing of the film away from the ship.

Similar nozzle additions were required to be made to another ship. The ship was ready to sail, passengers awaiting embarkation were being housed at local hotels at the ship's expense, the crew was being paid, pier and other charges were mounting, every hour of delay meant many dollars. Sam Tour & Co., Inc. field personnel, applying their new radiographic technique and field equipment, reduced the time required for each nozzle for setting up to less than an hour and the radium exposure time to 2½ hours. By taking portable dark-room film-developing equipment aboard the ship, the films were developed and viewed by the inspectors within 15 minutes after exposures were finished. The net result was the saving of several day of total time and a like advance of the sailing date of the ship.

The new techniques involved the making of a scale drawing to enable exact exposure calculations, the simultaneous use of two or more gamma-ray sources, the use of heavy lead shields to stop cross radiation, plus the use of portable dark-room equipment.

The *Electronik* Line



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The Month's NEW INSTRUMENTS

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Electron Microscope

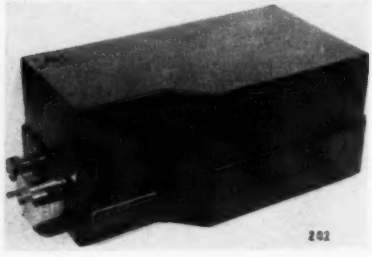
New "Little Giant" electron microsope, 30 in. high, provides direct magnification up to 6000 dia. with additional blow-up to 50,000 dia. through photographic enlargement. Depth of

focus is 150 times greater than best optical microscopes. Instrument may be operated with less than an hour of instruction. Specimens may be inserted into evacuated column without breaking vacuum. Pumping time between exposures is 90 sec. Permanent-magnet lenses provide exceptional stability.—*RCA Victor Div., Radio Corporation of America, Camden, N. J.*

Mention No. 601 when filling out card.

Double Monochromator and Spectrometer

New spectroscopic analyzer for range 0.2 to 35.0 microns uses a double monochromator to reduce scattered radiation to a minimum. Instrument can be operated manually or motor driven. Prisms are mounted on keyed holders and may be interchanged without read-

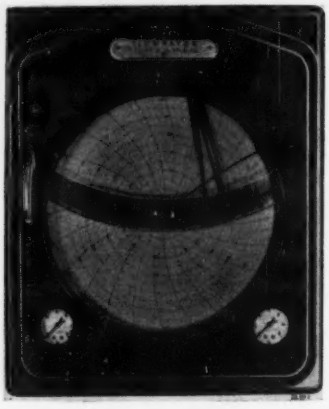


justment. Cams provide automatic control of wavelength and slit width. Various sources and detectors such as thermocouples, bolometers, photo tubes, thermopiles, sulphide cells, and gaseous detectors may be employed. Galvanometers, photometers, amplifiers, and recording systems may be linked to instrument. With auxiliary components it may be used as a double monochrometer, a double spectrometer, or a double spectrophotometer.—*Farrand Optical Co., Inc., Bronx Blvd. & E. 238 St., New York 66, N. Y.*

Mention No. 602 when filling out card.

Temperature and Pressure Instruments

New measuring, exhibiting and controlling temperature and pressure instruments are announced. Temperature instruments ("Ratotherm") have thermal systems filled with liquid, vapor-liquid or gas covering ranges be-



tween -125 F. and 1000 F. Pressure instruments ("Ratogage") have bellows, multiple-diaphragm, slack-diaphragm or helical pressure-measuring elements covering ranges between 30 in. mercury vacuum and 10,000 psi. Available are combinations of temperature, pressure, flow, etc. in one instrument case; also "Type 3 Pneumatrol" unit with proportional band, automatic reset and derivative action control.—*Fischer & Porter Co., 86 County Line Road, Hatboro, Pa.*

Mention No. 603 when filling out card.

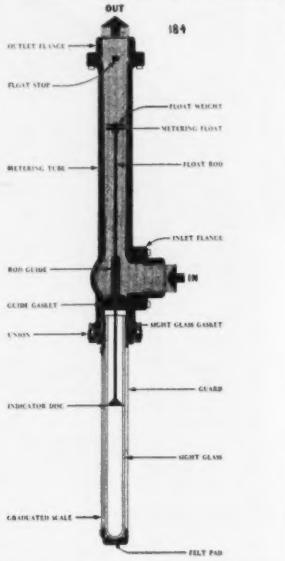
Rapid-pen-speed Millivolt Recorders

New models of multi-point "ElectroniK" strip chart potentiometers have full-scale pen speeds of two seconds or less for laboratory requirements; are suitable also for use with maker's "Radiamatic" units for sensitive radiation measurements. Calibrated accuracy is 0.375 percent of scale. Control or alarm contacts can be provided.—*Brown Instruments Div., Minneapolis-Honeywell Regulator Co., Wayne and Roberts Avenues, Philadelphia 44, Penna.*

Mention No. 604 when filling out card.

Flow-rate Indicators

New "Flo-Scope" variable-area flow-rate indicators are individually calibrated, under laboratory conditions

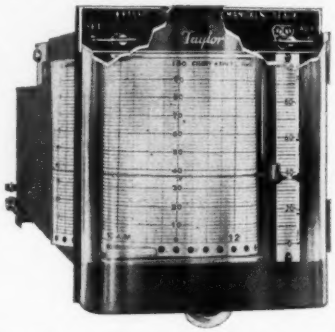


without time limitation, for characteristics of gases that are to be measured. —*Selas Corp. of America, Philadelphia 34, Pa.*

Mention No. 605 when filling out card.

Miniature Recorder

New "Transet" Recorder is a miniature recording-receiving instrument for pneumatic transmission of flow, liquid level, pressure and temperature, said to be ideally suited for either



graphic or convential panels. It fits into a panel opening of 3.875 x 4.5 in. with a flange measurement of 4.375 x 5 in. Clear plastic door gives full view of chart, scale and all principal instrument settings; allows maximum illumination. With door opened, adjustments can be made for instant checking

ALNOR THERMO-ANEMOMETER Here's a compact, direct-reading instrument that fills a long-felt need—the accurate measurement of low air velocities. With the Alnor Thermo-Anemometer you can accurately read velocities as low as 5 f.p.m. It can be used between 20°F. and 150°F. without impairing its accuracy. Fine craftsmanship, high-quality materials, exact calibration, and exhaustive tests combine to assure you accurate operation on a wide variety of applications.

ALNOR ELECTRONIC TEMPERATURE CONTROLLER . . . is a simplified form of controller designed to indicate and regulate automatically the heat of any industrial heating device. There are no moving mechanical parts to wear or cause trouble. Control sensitivity is such that pointer movement of 0.3% will activate the power relay. Available with a wide variety of thermocouples and in scale range from 0-500 to 0-3000°F.

ALNOR DEW POINT INDICATOR . . . for simple, rapid dew point reading of any gas. Indication takes place in an enclosed observation chamber under accurately controlled conditions. Dew or fog suspended in air—not on mirrored surface—makes it easy for two or more observers to get same accurate results. The Alnor Dewpointer is a complete, self-contained unit—no external coolant or other apparatus is required. Available for dew points from −80° F. to room temperature.

ALNOR TYPE 2300 SURFACE PYROMETER . . . sets a new high in precision measurement of low surface temperatures. Special design, from Alnico magnet to the finest, quick reacting thermocouple, assures unfailing accuracy . . . speed and dependability. This is a self-contained, sturdy unit—easily carried and used anywhere on a wide variety of applications. Direct reading, six-inch mirrored scale is easily read . . . quickly understood. The instrument is available in 5 Fahrenheit scale ranges with a span as small as only 150°.

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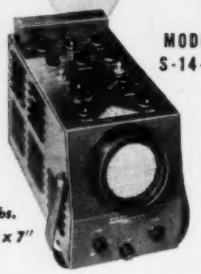

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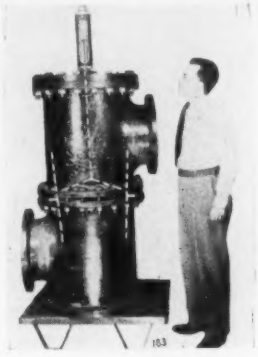
of valve position and for automatic-manual service. Set-point adjustment is made by knurled knob at bottom of case. Two micrometer screws above automatic-manual lever provide a convenient means for making zero adjustments for pen and set-pointer. Chart travels from right to left, one inch per hour, to produce a record similar to one which would be plotted by an engineer. Charts may be torn off from left side as needed. Electrically-driven chart mechanism is designed to pull out like a camera. Scale at right shows actual process range of transmitter and graduated 3 to 15 psi. for noting valve position and checking calibration. Four forms (all receivers 3 to 15 psi.) are available: (1) one process record, set-point indication, set-point adjustment, valve position indication and automatic-manual unit for use with controllers located in the control house; (2) one process record, set-point indication, set-point adjustment, valve position indication and automatic-manual unit for use with field mounted controllers; (3) one process record, valve position indication and remote manual valve loading; (4) one process record only.—*Taylor Instrument Companies, Rochester* 1, *N. Y.*

Mention No. 606 when filling out card.

Variable-area Flowmeters

New sizes of "Ratosleeve" variable-area flowmeters permit standardization on one type of meter for all capacities encountered in plant. Flow rates from 2 to 6200 GPM and from 3 to 12,500

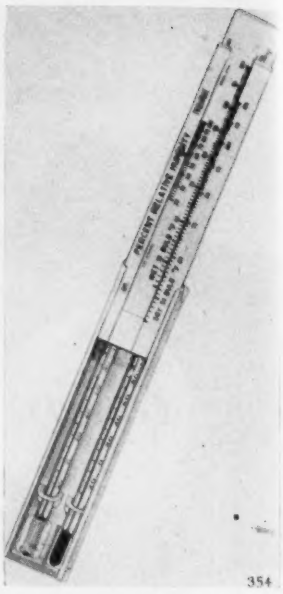


CFM are handled with a minimum number of basic metering parts designed for installation inside standard pipe fittings. Mountings for indicators, controllers, recorders, integrators and telemetering instruments are interchangeable in all sizes.—*Fischer & Porter Co., Hatboro, Pa.*

Mention No. 607 when filling out card.

Pocket Psychrometer and Humidity Rule

Now "TAG Pocket Humidicator Model 8704," shorter than a pencil, shows relative humidity by the wet-and-dry bulb method; can be used either in the hand or mounted on a wall. A built-in slide rule converts wet-bulb and dry-bulb readings into relative humidity, eliminating charts or tables. Both etched-scale glass thermometers are individually hand-calibrated; are secured in a white plastic case by integral resilient mountings. To



use instrument, a few drops of water are applied to thermometer wick and instrument is fanned or swung for several moments. Setting wet-bulb reading opposite dry-bulb reading on slide rule then indicates relative humidity.—*Weston Electrical Instrument Corp.*, 614 *Frelinghuysen Avenue, Newark* 5, *N. J.*

Mention No. 608 when filling out card.

Automatic Computing System for Retail Stores

New automatic computing system for stores can give, at the moment of happening, an accurate picture of how sales are going in each department and division as well as the store as a whole. System is said to be a simple one: commercial utilization of maker's standard instrument components developed for computing and control requirements of U. S. defense establishments. System begins at each cash register with a transmitter and ends in executive offices where data are computed and made visible. Sales indicators read in terms of a percentage of day's quota. This can be instantly converted into dollar sales for each department, division or total store by pressing a button. Continuous readings on indicators are accurate within pointer-and-scale limits, but final readings are digital: exact figures for accounting, obtainable immediately upon store closing.—*Arma Corp.*, 254 *36th St., Brooklyn, N. Y.*

Mention No. 609 when filling out card.

Stereoscopic Microscope

New "No. 20" stereoscopic microscope incorporates enhanced three-dimensional vision, wide and flat fields, comfortable angle of vision, dustproof nosepieces, and enclosed gearing for interpupillary-distance control. To extend or reduce focusing range, raise or lower head of instrument to any of three positions by removing and replacing a thumb screw. Stage is of platen type; instrument finish is satin-smooth

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Standard Equipment on GRAPHIC PANELS

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Uses the precision Nullmatic Regulator

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Installation	Application	Graphic Panel Engineering
★★CONTINENTAL OIL CO. Denver, Colo.	TCC Cracking Unit 4,800 bbl./day	Lummus
★COSDEN PETROLEUM CORP. Big Spring, Texas	UOP Fluid cat. 6,000 bbl./day	UOP Panellit
★DEEP ROCK OIL CO Cushing, Okla.	UOP Fluid cat. 5,000 bbl./day	UOP Panellit
★GLOBE OIL & REF. CO. Lemont, Ill.	UOP Fluid cat. 6,000 bbl./day	UOP Panellit
★INDIANA FARM BUREAU Evansville, Ind.	Complete refinery 5,000 bbl./day	UOP Panellit
★OLD DUTCH REFINING CO. Muskegon, Mich.	UOP Platformer 1,500 bbl./day	UOP Panellit
PAN AM SOUTHERN CORP. El Dorado, Ark.	Delayed coker 9,300 bbl./day	Lummus G E
★ROCK ISLAND REF. CO. Indianapolis, Ind.	Complete refinery 10,000 bbl./day	UOP Panellit
SHELL OIL CO. OF CANADA Montreal, Quebec	Solutizer 7,000 bbl./day	Shell Peacock
SOCIETE GENERALE Dunkirk, France	Dist. 26,000 bbl. day Lube 9,000 bbl. day	Lummus
STANDARD OIL CO. (OHIO) Lima, Ohio	Dist. 9,000 bbl. day Lube 3,500 bbl. day	Lummus G. E.-Sohio
SUN OIL CO. Toledo, Ohio	Houdriflow cat. 30,000 bbl./day	Sun-Houdry Panellit
★TIDEWATER ASSOC. OIL CO. Drumright, Okla.	Houdriflow 4,500 bbl./day	Panellit
★WOOD RIVER OIL & REF. CO. Hartford, Ill	UOP Fluid cat. 7,500 bbl./day	UOP Panellit

★ = On Stream by May 5, 1950 ★★ = First on Stream

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For Cyanide and Salt Baths

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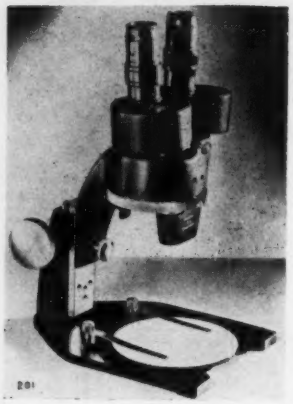
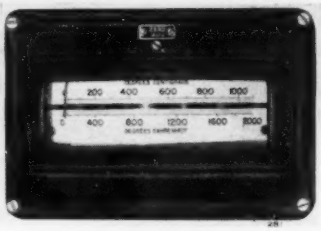


baked enamel. Microscope is available with single, double, or triple nosepieces; vertical or inclined binocular bodies; and a wide selection of objectives and eyepieces.—*Instrument Div., American Optical Co., Southbridge, Mass.*

Mention No. 610 when filling out card.

Indicating Pyrometer

New "Model 192" indicating pyrometer is available in usual ranges, but is designed for economy of space. Front

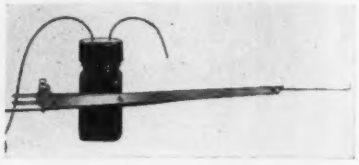


dimensions are 7.5 by 5 in. Net weight is 3.5 lb. A high-resistance "edgewise" movement with Alnico V magnet and mirrored scale is fully compensated and enclosed in dustproof housing.—*Wheelco Instruments Co., 847 W. Harrison St., Chicago 7, Ill.*

Mention No. 611 when filling out card.

Recording Chart Pen

New automatic recording chart pen, said to write for several months without servicing, works on capillary principle using closed system; utilizes



bottled-ink reservoir. Small flexible tube leads from bottle to pen; ink feeds at same rate used and never blurs; uses regular or fast-drying inks. Weight does not vary with ink supply. —*American Recording Chart Co., 3115 E. 11th St., Los Angeles 24, Calif.*

Mention No. 612 when filling out card.

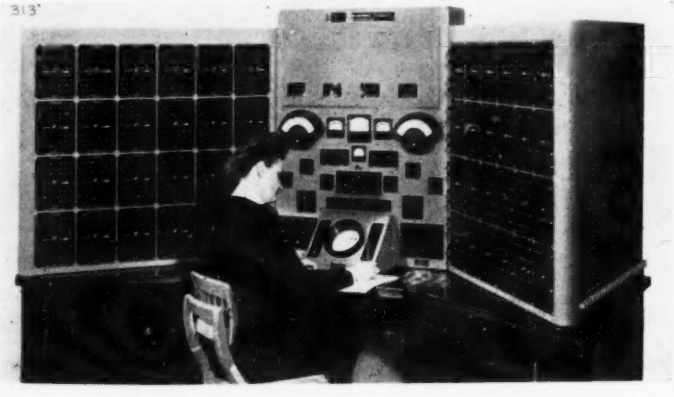
Recording Flowmeter Manometers

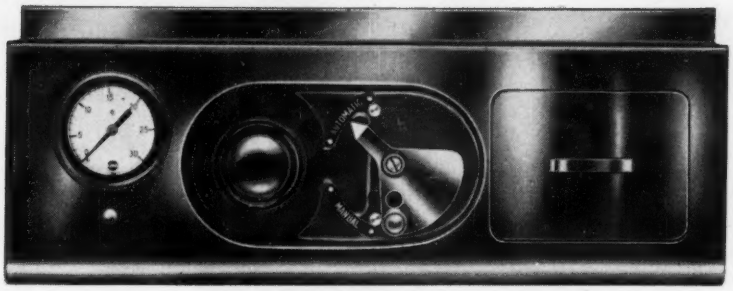
New line of mercury manometers has been developed to utilize maker's magnetic-clutch or impedance-bridge type of transmitter, as originally used with variable-area flowmeters, in cases where a manometer is called for. Transmitters require no pressure-tight bearings or stuffing boxes; are adaptable to electric or pneumatic trans-

Principal Strain Computer

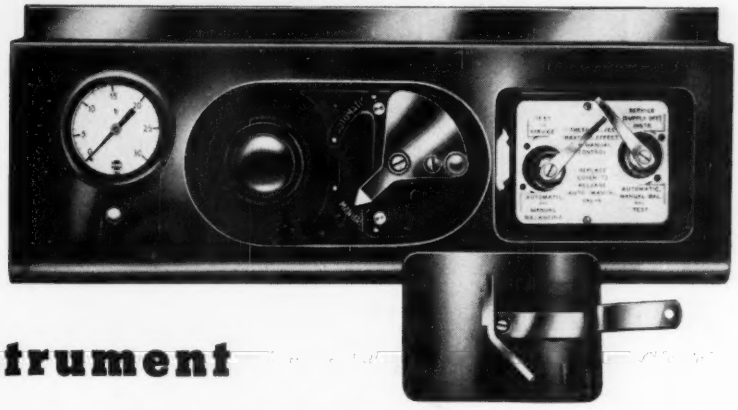
New instrument for automatically computing and indicating principal strains operates directly from strain-gage rosettes, indicating almost instantaneously the values of major principal strain, minor principal strain, and the principal angle. It operates with equiangular rosettes, rectangular rosettes, and with Tee-Delta rosettes. A single selector switch converts from one equation to another. Sum and difference factors are obtained by networks, operating directly on outputs of individual gages. Square-root of sum of several squares is obtained almost instantaneously by a self-balancing electrodynamometer. A total of 48 rosettes (either 3-gage or 4-gage) may be connected to new computer and each gage properly balanced before strain determinations are made. Built-in calibrating equipment is provided.—*Hathaway Instrument Co., 1315 S. Clarkson St., Denver 10, Colo.*

Mention No. 613 when filling out card.





No other control instrument



has an external manual-automatic station as mistake-proof as this

***EXCLUSIVE** mechanical interlock prevents switching into wrong position*

***EXCLUSIVE** "balancing" arrangement prevents "bumping" on changeover*

Among the many features which have put the Bristol Series 500 Air-Operated Controller way out front is the unique External Manual-Automatic Station.

1. "Test" and "Service" positions are mechanically interlocked. Operator cannot, by mistake, go *through* "Manual" position into either "Test" or "Service."

2. Output pressures of the controller and the regulator on panel are measured by the *same* gauge. This enables operator to achieve exact *balance* before going from automatic to manual control or vice versa, thus eliminating the possibility of a "bump" to the process during changeover.

Bristol's External Manual-Automatic Station is an integral part of the controller installation . . . yet can be used independently for manually controlling the process *before* the controller is installed or *after* it has been removed for any reason.

Read what else Bristol Series 500 Controller gives you . . . calibrated control, single service adjustment, reset stops, etc. Write for new Bulletin A120 on Series 500 Air-Operated Controllers, THE BRISTOL COMPANY, 113 Bristol Road, Waterbury 20, Conn.

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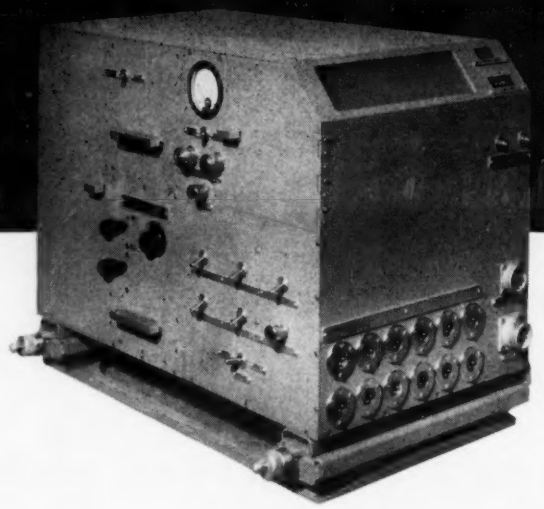
AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

Century MODEL 406

RECORDING OSCILLOGRAPH FOR VIBRATION — TEMPERATURE STRESS — STRAIN ANALYSIS

where any or all of the above information is an important factor.



FEATURES

1. 12—50 individual channel recording.
2. Continuous recording up to 200' without jamming
3. Instantaneous changes of recording speeds up to 50" per second with automatic adjustment of lamp intensity.
4. Timing System — Discharge lamp controlled by temperature compensated tuning fork providing sharp .01 second with heavier .1 second timing lines. Conversion to .1 second lines only, by switching.
5. Independent optical system provides constant view of traces with optimum light intensity at all times.
6. Recording lamp under constant surveillance of external condition indicator lamps.
7. Galvanometers — with optional range of frequencies and sensitivities.
8. Electrical — Available for operation from option of 12 or 24 volts D.C., or 110 volts A.C.

OPTIONAL FEATURES

1. Trace identification by means of light interruption.
2. Trace scanning for observation of steady state phenomena.
3. Remote control unit.
4. Automatic record numbering system.
5. Automatic record length control.
6. Visual paper footage indicator.

For additional information write

Century GEOPHYSICAL CORPORATION
TULSA, OKLAHOMA

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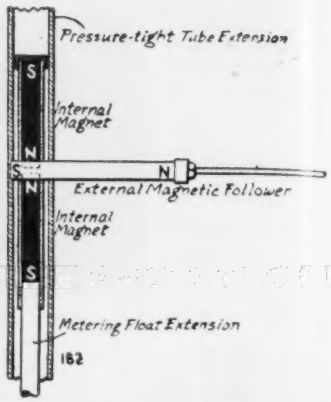
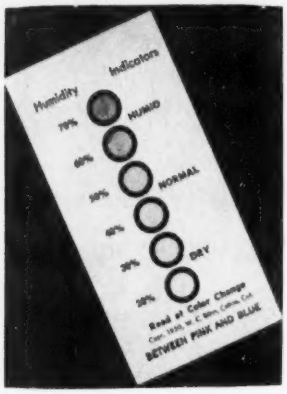


mission of signals. Instruments will stand up to 1500 psi. and are supplied in ranges of up to 35, 50, 100, 200, and 400 in. water.—*Fischer & Porter Co., Hatboro, Pa.*

Mention No. 614 when filling out card.

Humidity-indicating Printed Cards

New humidity-sensitive cards, selling for only a few cents, represent a radical innovation in field of humidity measurement. Six graded hygroscopic materials are printed in a row of 0.4-

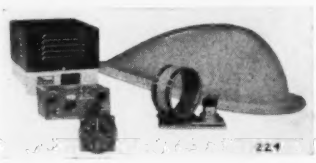


in. circles. Color change tells at a glance relative humidity over range 20 to 70 percent with an accuracy of about 5 percent. At very high humidity, colors will run, indicating that near-saturation has been reached. Indicator is reversible and will not dust off.—*Humidial Co., 864 Edgehill, Colton, Calif.*

Mention No. 615 when filling out card.

Automatic Direction Finder for Aircraft

New "Model ADF-12" automatic direction finder consists of a tuner, amplifier, azimuth indicator and loop as-



sembly. Unit meets USAF and CAA design requirements for use in jet, transport, executive, liaison and personal aircraft. Weight is 18 lbs.—*Lear, Inc., Aircraft Radio Div., 110 Ionia Ave. N.W., Grand Rapids 2, Mich.*

Mention No. 616 when filling out card.

Film-thickness Gage

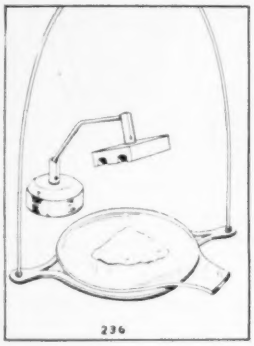
New thickness gage for measuring dry films operates by stripping film from base, and then noting with optical system the distance necessary to

move an eccentric wheel to touch film while supports are resting on stripped base. For measuring metal, foil, paper, or plastic film thickness, a feeler gage principle is used. High accuracy is claimed because no pressure is exerted against measured surface.—*Henry A. Gardner Lab., Inc., 4723 Elm St., Bethesda 14, Md.*

Mention No. 617 when filling out card.

Static Eliminator for Analytical Balances

New "Model M" static eliminator uses harmless quantity of polonium as

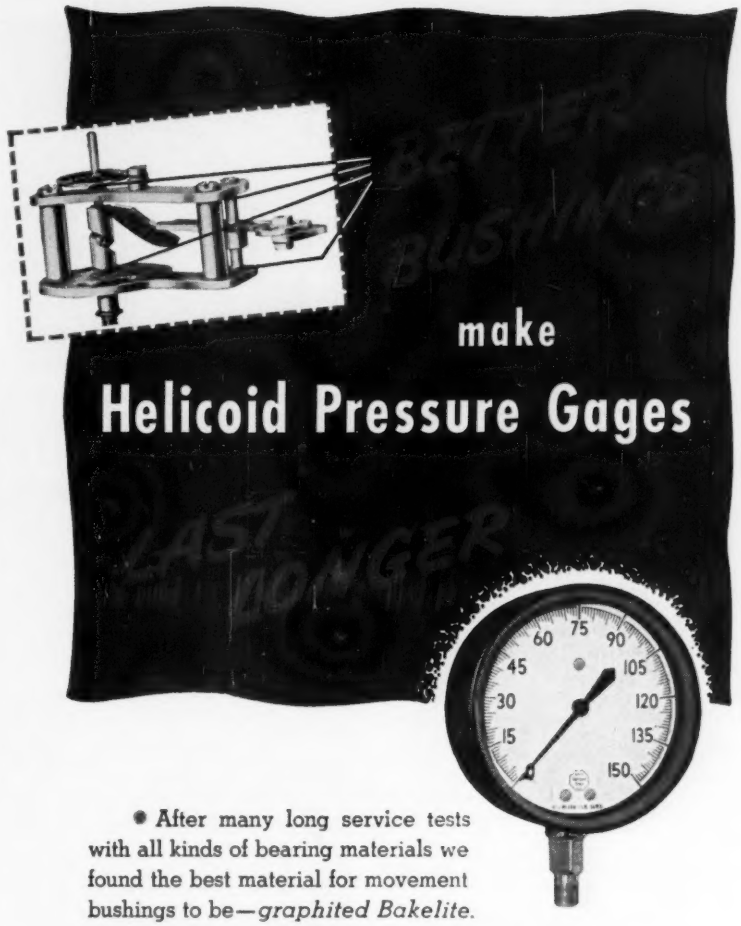


a source to ionize air in vicinity of balances to discharge static electricity. —*E. Machlett & Son, 220 E. 23rd St., New York 10, N. Y.*

Mention No. 618 when filling out card.

Reid Vapor Pressure Bombs

New light-weight Reid Vapor Pressure Bombs suitable for testing aviation gasolines, according to revised ASTM Method D-353-49, are also suitable for ordinary gasoline, benzol blends and volatile liquids. Volume ratio of air chamber to gas chamber has been held within close limits set for testing aviation gasolines. Without pressure gage, immersion sampling bombs weigh

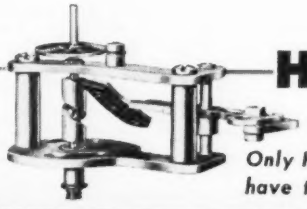


• After many long service tests with all kinds of bearing materials we found the best material for movement bushings to be—*graphited Bakelite.*

Graphited Bakelite bushings outwore all others—ran 50,000,000 full stroke cycles at 700 cycles a minute with negligible wear, no corrosion, no distortion from impact.

Among other tests, one of the largest public utilities found that HELICOID GAGES with these bushings lasted four times longer than any other gage tested under the same severe conditions.

Helicoid movements with graphited Bakelite bushings have less static and kinetic friction. They are now standard in all Helicoid gages—at no extra cost.



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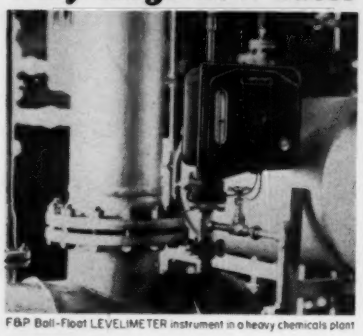

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USES?

Measurement, Exhibition, and Control of Liquid & Interface Level . . . and Weir & Flume Level for very large flow rates

SPECIFICATIONS?

Maximum Travel	25 feet	10 inches
Sensitivity	⅛ inch	1/100 inch

Adapted for extremely corrosive service

Available without stuffing boxes, pressure-tight bearings and mechanical linkages

Pressures and temperatures limited only by acceptable materials of construction

TYPES?

Automatic Control

Single- or multi-level, close-coupled or remote exhibition (indicating, recording or both)

Primary Element	Operating Range
Ball-Float:	
Direct-Acting	2", 5" and 10"
Lever-Acting	determined by installation
Pneumatic: Bubbler and Diaphragm	12 inches and above
"Doughnut"	up to 25 feet
Differential-Pressure Manometer	400 inches H_2O measurement - zero suppression possible
Displacer-Buoy	determined by installation

Coupling: Electric, Electronic, Magnetic

Transmission: Electric (Inductance Bridge and Selsyn), Electronic, Pneumatic

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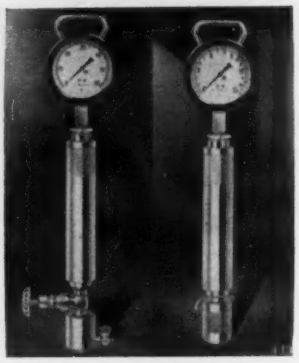
PROCESS CONTROL INSTRUMENTS

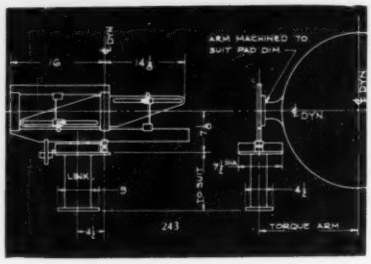


3 lbs.; pressure sampling bombs 4.5 lbs. Both new bombs are guaranteed accurate to within 0.5 percent of scale range.—*Precision Scientific Co.*, 3737 *W. Cortland Ave., Chicago* 47, *Ill.*

Mention No. 619 when filling out card.

Adjustable Linkage for Dynamometry

New "Uni-Beam" linkage for torque measurement offers continuously-adjustable cable assemblies for a wide range of torque selection. Instrument

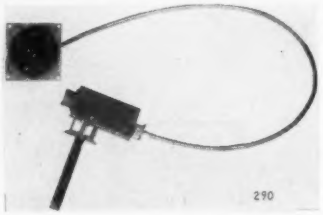


produces air-pressure output which is linear with respect to torque, and is accurate to one-tenth percent.—*Link Engineering Co.*, 13845 *Elmira Ave., Detroit* 27, *Mich.*

Mention No. 620 when filling out card.

Aircraft Thermostat

New "FYLD" duct thermostat for aircraft heater control is equipped with a flexible cable for remote control-point adjustment from cockpit or flight-attendant station. It compensates for



variations in duct air velocity. Stand-off flange mounting eliminates variations in calibration with changes in ambient air temperature. Maximum thermostat operating temperature is 450 F.; maximum range is 200 F. Electrical components are explosion proof.—*Barber-Colman Co., Rockford, Ill.*

Mention No. 621 when filling out card.

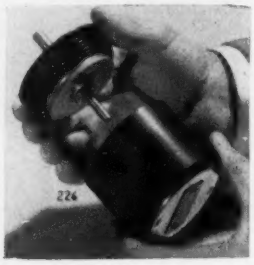
Automatic Barrel Filler

New automatic barrel filler will handle volatiles and crude-viscous residue with equal efficiency. Automatic check valve operates when barrel is full, thus preventing overflow.—*The Pennsylvania Flexible Metallic Tubing Co.*, 7200 *Powers Lane, Philadelphia* 42, *Pa.*

Mention No. 622 when filling out card.

Yarn-tension Controller

New yarn-tension controller uses a magnetic drag, or hysteresis effect, to apply tensions to yarn of different sizes

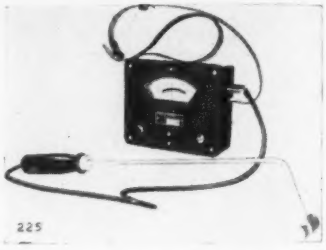


adjustable over a range of 3.5 to 10.5 gram-inches at speeds up to 700 yards per minute.—*General Electric Co., Schenectady* 5, *N. Y.*

Mention No. 623 when filling out card.

Tin-content Indicator for Solder

New "Model 2872" of maker's tin-content indicator originally described with three illustrations on p. 810, Sept.



'48 *Instruments*, will determine up to 7 percent tin content in lead alloys in a matter of seconds.—*Wheelco Instruments Co., Chicago* 7, *Ill.*

Mention No. 624 when filling out card.

Contour Recorder

New "Model MTR-1" contour recorder is designed to obtain records of tooth forms, thread forms and similar gearing, but is adaptable to other applications. Pen movement is 0.125 in. per 0.0001 in. of checker finger movement. Chart drives give 0.5 in. travel for either 2 or 1 degree of work rotation.—*Michigan Tool Co., Detroit, Mich.*

Mention No. 625 when filling out card.

Laboratory Balances

New line of laboratory balances is a complete re-design to take advantage of new corrosion-resistant alloys with

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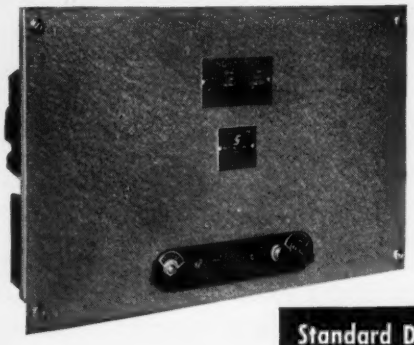
by sorensen

- **MAXIMUM ACCURACY**
- **MINIMUM DISTORTION**
- **FREQUENCY INSENSITIVITY**



Standard DC

*Output voltage	6	12	28	48	125
**Load in amperes	5-15-40-100	5-15-50	5-10-30	15	5-10
Input voltage	95-130 VAC single phase 50-60 cycles: adapter available for 230 VAC operation				
Regulation Accuracy	±0.2% from 1/10 to full load				
Ripple voltage RMS Max.	1%				
Recovery time	0.2 seconds — value includes charging time of filter circuit for the most severe change in load or input conditions				

*Adjustable +10%, —25%
**Individual models identified by indicating output voltage first then amperes. Example: E-6-5 6 VDC @ 5 amperes

Standard AC

Model in VA Capacity	150S 500S	250S 1000S	2000S 3000S	5000S 10000S 15000S
Regulation Accuracy	±0.1%	0.1%	0.1%	0.1%
Harmonic Distortion	3% max.	2% max.	3% max.	3% max.
Input voltage	95-130 VAC also available for 190-260 VAC single phase 50-60 cycles			
Output voltage	Adjustable between 110-120; 220-240 in 230 VAC models			
Load range	O — Full load			
P.F. range	Down to 0.7 P.F.			

NOTES: Regulators can be hermetically sealed.
All models temperature compensated.

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℞ STABILINE Automatic Voltage Regulators

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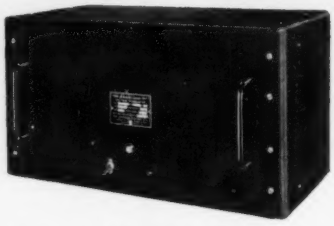
Voltage jitters in power lines are not only a nuisance but prevent proper operation of electrical equipment . . . cause faulty test results in laboratory and shop. STABILINE Automatic Voltage Regulators can remedy this undesirable condition; can give you the engineered control that will assure you of constant line voltage when and where it's most needed.

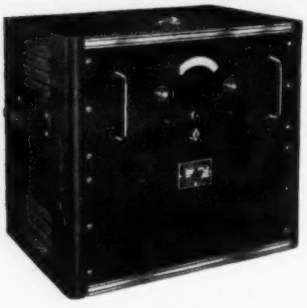
Two Stabiline Types are available



STABILINE TYPE IE

(INSTANTANEOUS - ELECTRONIC)

Completely electronic in operation; has no moving parts. Offers instantaneous action, to maintain output voltage to within ±0.1 volts of nominal for any line voltage variations; to within ±0.15 volts for any load current change or load power factor change from .5 lagging to .9 leading. Waveform distortion *never* exceeds 3%.



STABILINE TYPE EM

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For large installations where high efficiency, zero waveform distortion and low cost are important; where instantaneous correction is unnecessary. Delivers constant output voltage regardless of variations in input voltage or load current.

STABILINE Automatic Voltage Regulators are offered in a wide range of ratings, in cabinets or for relay rack mounting. Our new bulletin gives complete details on the STABILINE types IE and EM. Write for a free copy today.

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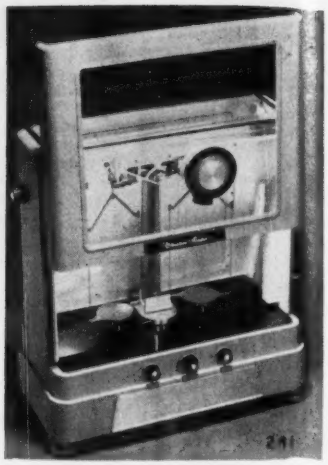
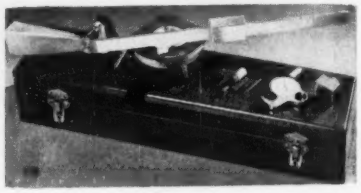


non-magnetic properties, the experience of leading chemists and technicians, and modern styling.—*Christian Becker Div., Torsion Balance Co., Clifton, N. J.*

Mention No. 626 when filling out card.

Shear-hardness and Diamond-scratch Tester

New "Model 139" shear-hardness and diamond-scratch tester is equipped with balanced-scale beam, calibrated in grams, to which is attached either a

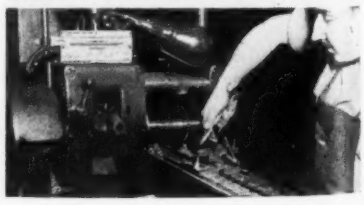


contour shear tool, or a diamond-point scratch tool. Sliding weight gives range 0 to 500 g. with extra weight to extend range to 1000 g. Specimen may be any thickness up to 0.25 in. Instruction book describes interpretation of measurements.—*Taber Instrument Corp., 111-I Goundry St., N. Tonawanda, N. Y.*

Mention No. 627 when filling out card.

Productivity Slide-rule

New "Productivity-Scope slide-rule has scales calibrated in terms of hours worked and hours earned, and recess for a job instruction slip. Rule is attached



directly to each machine, or placed on each worker's bench. When hourly output is below standard, the fact is indicated by a red signal. When job is in good shape, with production above normal, a green signal shows.—*R. G. Bock Engineers, 1951 Irving Park Road, Chicago 13, Ill.*

Mention No. 628 when filling out card.

Vernier Caliper

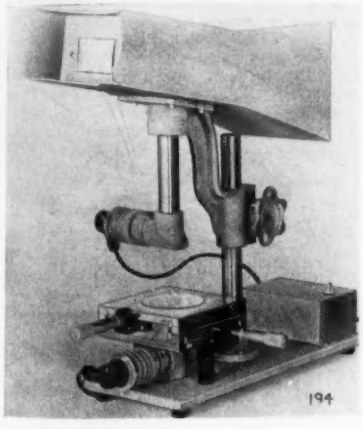
New "Model 64" Mauser caliper for outside, inside, and depth measurements has three scales: inches with

vernier to one-thousandth, fractions with vernier to one-hundred and twenty-eighth, and millimeters to tenths.—*George Scherr Inc., 200 Lafayette St., New York 12, N. Y.*

Mention No. 629 when filling out card.

Universal Projector

New universal projector is primarily a measuring instrument capable of reading in increments of ten-thousandths of an inch in two planes at 90 degrees, but also provides contour



and front-surface projection of subject. It is available in 10, 20, 30, 45, and 60 standard and special up to 120-times magnification. Screen is 6-in. square, made of textolite. Parts up to 5-in. high can be measured.—*Stocker and Yale, Marblehead, Mass.*

Mention No. 630 when filling out card.

Laboratory Millivolt Indicator

New laboratory-type electronic indicator for accurately measuring millivolts is being produced jointly by Rubicon Company and the undersigned. In this new instrument an "ElectroniK" indicator performs the functions of a galvanometer in detecting unbalance, hence reduces operator fatigue and increases potential work to be done. New instrument is designed for checking, calibrating and standardizing indicat-

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when you want it . . .

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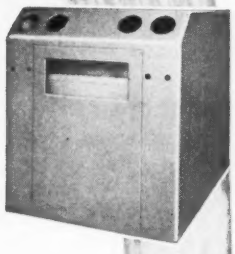

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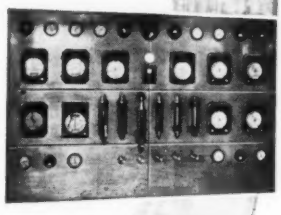

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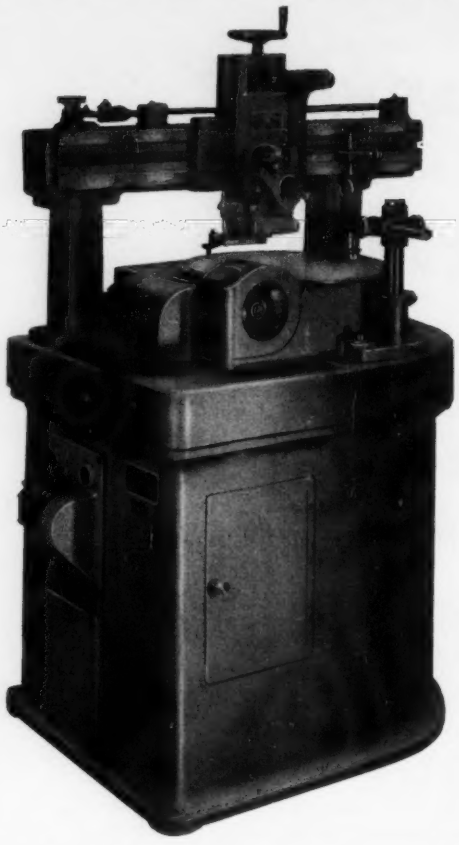

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ing instruments, potentiometers and thermocouples. It is said to "combine the high accuracy of the Rubicon laboratory-type potentiometer with the automatic null-type measuring circuit of Brown ElectroniKs." Readability and sensitivity, one microvolt; accuracy within three microvolts, or 0.02 percent of indication.—*Brown Instruments Div., Minneapolis-Honeywell Regulator Co., Wayne and Roberts Avenues, Philadelphia 44, Pa.*

Mention No. 631 when filling out card.

Phase Sequence Indicator

New "Model K-3 Knopp Phase Sequence Indicator" features several advancements in design; is for use on 60 to 600-volt circuits (as compared to maximum of 500 volts in model being superseded); can be used for

checking phase sequence of circuits having a frequency above normal 60 cycles by raising minimum circuit voltage above 60 volts, maximum frequency being 400 cycles. For example, it can be used to check 180-cycle circuits of 200 volts and more. Correct indication is given regardless of voltage or circuit conditions without changing taps or dials.—*Electrical Facilities Inc., 4250 Holden St., Oakland 8, Calif.*

Mention No. 632 when filling out card.

Insulation Tester

New low-cost insulation resistance tester is said to have advantages of maker's "Midget Megger" Tester, plus a new improved generator, flush ter-

minals and durable, modern-design plastic case. In addition, it is available with ohm scale and selector switch in ranges 0 to 10 megohms (100 volts), 0 to 20 megohms (250 volts) and 0 to 50 megohms (500 volts).—*James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

Mention No. 633 when filling out card.

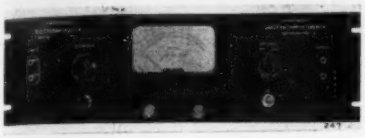
Electrical Resolvers

New mechanoelectrical components in two size groups developed particularly for electromechanical computing and control equipment are announced for apparatus using trigonometric functions.—*Arma Corp.*, 254 36*th St.*, *Brooklyn 32, N. Y.*

Mention No. 634 when filling out card.

Tuned Audio Amplifiers

New series of amplifiers provide pass frequencies and tuned frequencies of 400, 500, 1000, 2000, 3000, and 10,000 cps. Positive feedback is predominant

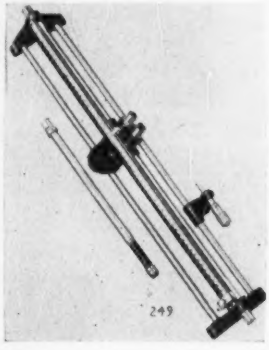


at pass frequency while negative feedback prevails throughout remainder of spectrum.—*Instrument Div., Amplifier Corp. of America*, 398-17 *Broadway, New York* 13, *N. Y.*

Mention No. 635 when filling out card.

Slotted Line and Coaxial Elements for UHF Measurements

New "Type 874-LB" slotted line and "Type 874" coaxial elements are said to provide a convenient and accurate system for impedance, standing-wave,



voltage and power measurements at ultra-high frequencies. Over-all standing-wave ratio is less than 1.02 at 1,000 megacycles, and constancy of probe penetration is better than 2.5 percent. —*General Radio Co.*, 275 *Massachusetts Ave.*, *Cambridge* 39, *Mass.*

Mention No. 636 when filling out card.

Infinite-impedance Probe for D-c. VTVM

New "PR6-NL" 1,000 to 1 capacitive d-c. divider probe is an ultra-sensitive current-measuring device to be used with maker's d-c. millivoltmeter, "Model MV-17b." Currents to be measured are fed into a 500 micromicrofarad capacitor for a definite period of time. A switch then transfers charge into

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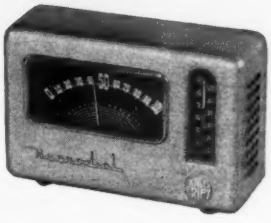

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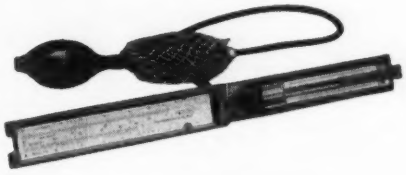

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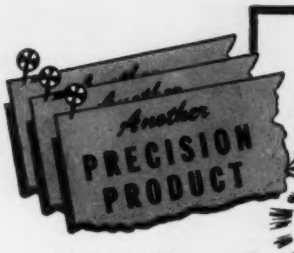

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The Burlington "Hermetically Sealed" *Instrument* was designed and is manufactured to conform to JAN specifications for sealed *instruments*.

- Steel case with heavy copper-cadmium plate and black finish.
- Excellent shielding due to case material and construction.
- Double strength clear glass.
- Black satin onodized aluminum bezel.
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- Available in 2½" and 3½" round case types.
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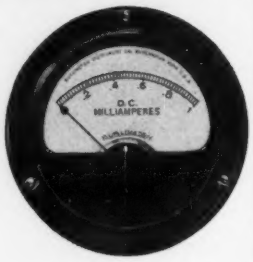

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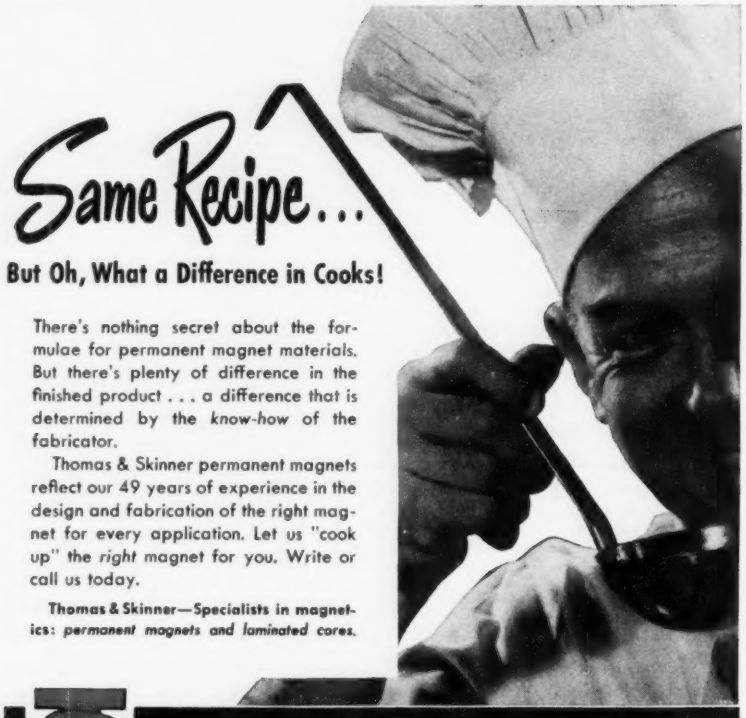

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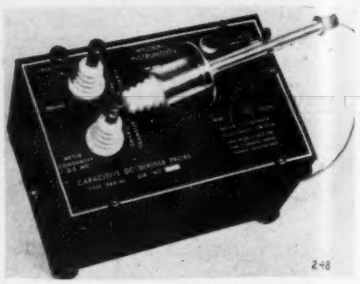
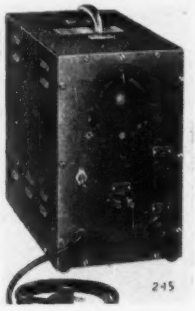


an 0.5 condenser supplying d-c. power to millivoltmeter. Current measurements down to a half micromicroampere can be made with a charging time of 50 sec. Probe can also be used for infinite-impedance voltage measurements between 1 v. and 30 v.—*Millivac Instruments, P. O. Box* 3027, *New Haven, Conn.*

Mention No. 637 when filling out card.

Regulated A-c. Voltage Supply

New "Type CVL" regulated voltage supply is designed for use with equipment that requires an adjustable source of constant a-c. voltage (from 0

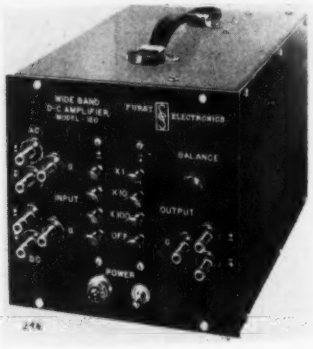


to 130 v.) of undistorted wave shape. Characteristics are 1-percent regulation for line-input changes from 95-125 v. with less than 3-percent harmonic distortion of input-voltage wave. —*Sola Electric Co.*, 4633 *W. 16th St., Chicago* 50, *Ill.*

Mention No. 638 when filling out card.

Wide-band D-c. Amplifier

New "Model 120" wide-band d-c. amplifier has an input impedance of 1 megohm at 20 micromicrofarads single end, or 2 megohms at 10 mmf. for



push-pull; frequency response of d-c. to 100,000 cps. within 1 db. and 6 db. down at 200,000 cps.; max. gain of 100; less than 40 microvolts noise and hum at input; and less than 1 millivolt drift after warm-up.—*Furst Electronics, 12 S. Jefferson St., Chicago 6, Ill.*

Mention No. 639 when filling out card.

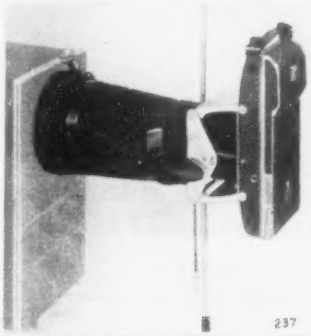
Pneumatic Current Controller

New "Model EB" pneumatic current controller utilizes a standard electrical component such as a rheostat or variable transformer modified for continuous throttling-control service, and a new pneumatic-cylinder operator which includes an integrally-mounted positioning device to provide accuracy and sensitivity of positioning to within 0.2 percent of its total travel.—*Conoflow Corp., 2100 Arch St., Philadelphia 3, Pa.*

Mention No. 640 when filling out card.

Oscilloscope Camera

New "F-284" oscilloscope camera is an adaptation of the Polaroid-Land Camera which delivers an accurate photographic record of single transients or repetitive phenomena without need for darkroom processing. A two-position over-center shift makes it possible to make two recordings on one print. Camera is designed for use with any standard 5-in. cathode-ray oscilloscope. Writing speeds up to 1 inch per microsecond have been recorded with an accelerating potential of 3000



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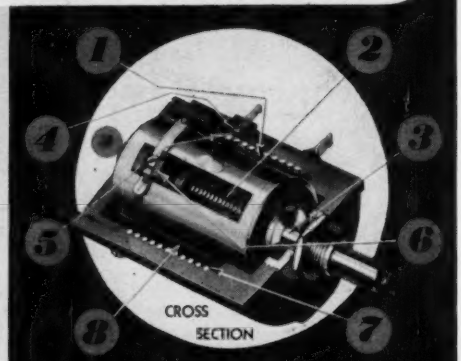

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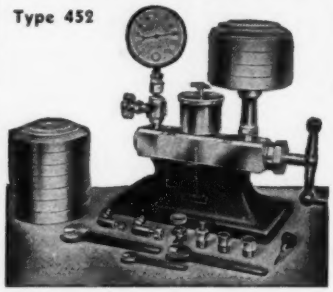

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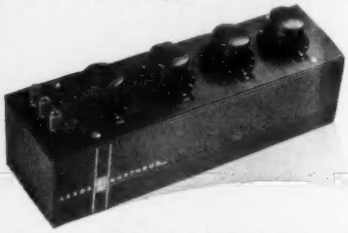
v. With higher accelerating potentials writing speeds up to 50 to 60 inches per microsecond are possible. Print size is 3.25 by 4.25 in. with two recorded images reduced by a ratio of only 2 to 1 from original trace.—*Fairchild Camera and Instrument Corp.*, 88-06 *Van Wyck Blvd., Jamaica 1, N. Y.*

Mention No. 641 when filling out card.

Resistance Boxes

New resistance boxes are designed for use as standards for d-c. and for a-c. resistance measurements up to medium frequencies. New type of rotary switch has solid-silver contacts and silver-alloy multiple-leaf brushes. Zero



or contact resistance is less than 0.002 ohm per decade and changes less than 0.0005 ohm per decade on accelerated life tests. Limit of error is plus or minus (0.05 per cent plus 0.0005 ohm). 4-dial model has a range of 11,110 ohms in 1-ohm steps. 5-dial models cover 11,111 ohms in 0.1 ohm steps or 111,110 ohms in 1-ohm steps. Time constant at 50 kc. is less than 0.05 microsecond.—*Leeds & Northrup Co.*, 4934 *Stenton Ave., Philadelphia* 44, *Pa.*

Mention No. 642 when filling out card.

"Light-spot-pointer" Type Electrical Instruments

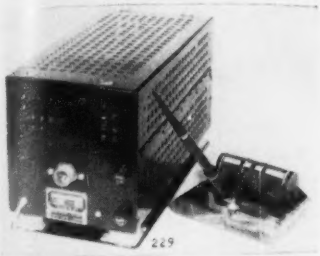
New 28.25 in. scale electrical instruments with spot-of-light pointer can be furnished with any type of movement or sensitivity normally obtainable as micro, milli, or ammeters and milli or voltmeters in a-c. or d-c. types;

rectifier, thermo, RF, watt, pyro, or tachometers; strain-gage indicators and similar instruments. They can be calibrated to as close as 0.25 percent of full-scale value. Single instruments are 18.25 by 22.875 by 7.25 in. and weigh 34.75 lbs. Dual instruments measure 25.5 by 52 by 10 in. and weigh 158.5 lbs. Instrument is housed in a heavy welded-steel case with black-wrinkle finish.—*Cole Instrument Co.*, 1320 *South Grand Ave., Los Angeles, Calif.*

Mention No. 643 when filling out card.

Electronic Inverter

New "Model 421" electronic inverter transforms 28 v. d.c. to 400 cps. within one-tenth percent, 115 v. single phase and 115 v. three phase. Features are

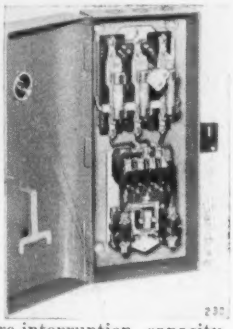


frequency and voltage stability, over extreme ranges of temperature and altitude, load and input ranges, and absence of moving parts. Output is 100 VA, power factor 0.4 to 0.8 lag, weight 19 lbs., volume 620 cu. in.—*Varo Mfg. Co., Box 638, Garland, Tex.*

Mention No. 644 when filling out card.

Magnetic Starters

New "Bulletin 4120" magnetic starters with disconnect switches, fusible and non-fusible type, feature front operation, thermal-overload protection,



high arc-interruption capacity, provision for padlocking in on and off position and interlock protection in on position. Starters are available in four standard sizes to 50 H.P., 3 Ph., 550 v., 60 cps. max.—*Ward Leonard Electric Co., Mount Vernon, N. Y.*

Mention No. 645 when filling out card.

Voltage Tester

New "Model 1601" voltage tester affords full protection against exploding or serious arcing even when accidentally applied to a voltage as high as 4800 for as long as two seconds. Indication of 120, 240, 480 or 600 v. a.c. circuits

MICRODIAL

TEN TURN-COUNTING DIAL

Microdial is composed of two concentrically mounted dials . . . one for counting increments of each turn and the other for counting turns. The incremental dial has 100 equal divisions and is attached rigidly to the shaft so there is no backlash. Thus the contact position is indicated to an indexed accuracy of 1 part in 1000. Rotation is continuous in either direction. There are no stops on the Microdial assembly.

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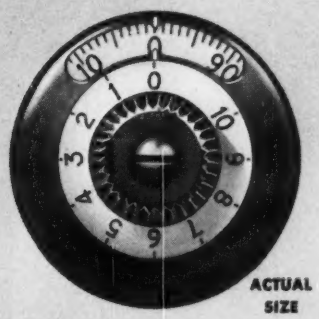
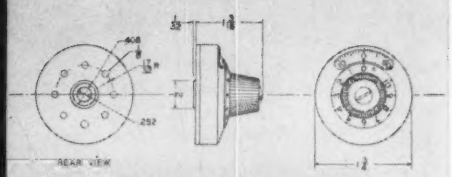
CLEAR READING . . . Forced fast-reading tests showed only 1/20th as many errors with Microdial open window as with next most legible dial. Turn counter distinguishes between 0 and 10 turn readings, and accelerates to avoid confusion on readings near integral turns. Precise readings are made from larger dial with maximum separation of graduations and wide angle visibility.

CONVENIENT . . . delivered completely assembled with dials synchronized. Easily mounted in a few seconds. All dials may be locked.





Microdial . . . turn-counting dial, primarily designed for use on Micropot ten turn linear potentiometers . . . use it on any multiturn device having ten turns or less.

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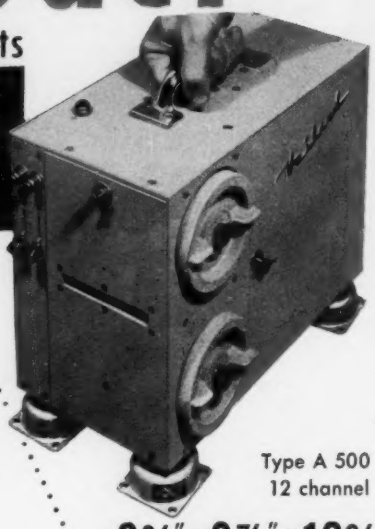

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12 channel

6¾" x 9⅞" x 12¾"

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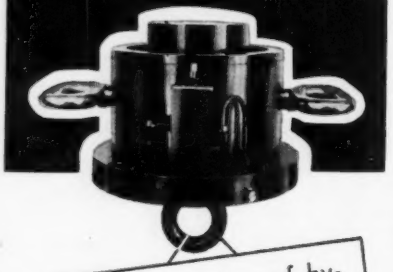

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is definite. 25 or 60-cps. current is identified positively. Tester employs 4 neon tubes mounted in barrel of probe. One lamp glows on 120 v., two on 240 v. and three on 480 v. circuits. Fourth glows on 600 v. circuits and indicates an abnormal secondary voltage such as a cross with primary circuit.—*The Elwood Co.*, 410 *W. Seneca St., Buffalo 2, N. Y.*

Mention No. 646 when filling out card.

Oscillosynchroscope

New "Model ON-5" oscillosynchroscope, designed to provide wide-band amplifier and versatile sweep facilities in single portable unit, is particularly suited to study of pulse and transient phenomena. Vertical amplifier response is flat within 3 db. from 5 cycles to 5 mc. Horizontal amplifier is direct-coupled with high frequency

response extending to 500 kc. Sweep generator may be triggered on recurrent with direct-reading writing-rate calibration for any internal sweep condition. Triggered sweep speeds from 1.0 to 25000 microseconds per inch and recurrent sweeps of 10 to 100 kc. are available. An adjustable calibration voltage may be used for determination of vertical deflection voltage amplitudes. Either d.c. or a.c. connection may be made to all deflection electrodes. Also provided is a panel connection to CR tube cathode for external beam modulation. Height 14.5 inches; weight 50 lbs.—*Browning Laboratories, Inc., Winchester, Mass.*

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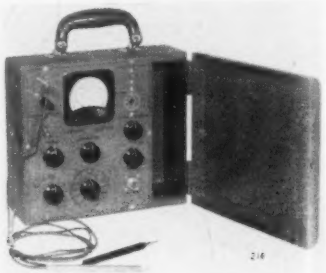
Multi-purpose Electrical Tester

New "Type EX-1C" electrical tester is designed for use with equipment operating in 25-50, 72-76 and 148-174 Mc. bands to align sensitive land-mobile communication receivers which re-



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LEVEL INDICATOR

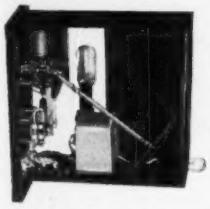
Pneumatic Operated Receiver

YOU ACTUALLY SEE the levels on this new ILLUMINATED direct-reading dial

Model 240

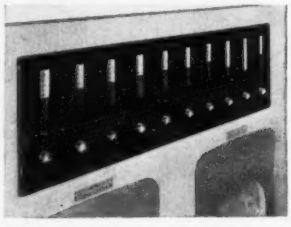
The moving red column shows every dip and rise in levels clearly, at a great distance. For sensitive and accurate reading of levels in Tanks, Boilers, Towers or for indicating valve loading position.

Operates from any 3-15 lb. transmitter. A precision instrument of many uses.



"Drawer" type unit makes it easy to remove entire mechanism.

Receivers may be equipped with positive "high" and "low" level mercury alarm switches adjustable throughout the range. Warning horn and signal lights may be operated by standard PANALARM annunciator unit in receiver, as added protection.



Receivers can be arranged for flush panel mounting in any multiples. Strip type dial design conserves panel space. Easy to install — easy to pipe and wire.

Bulletin 240 is now available. Write for it today.

PANALARM PRODUCTS INC.
A Division of PANELLIT INC.
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quire a very weak signal. A crystal-diode pickup head permits comparative measurement of antenna-power output. Instrument contains a full range of current and voltage scales as well as a resistance scale. Complete test unit includes basic instrument, crystal-diode pickup, head-phone plug test lead, and RF interconnecting lead. —*Commercial Equipment Div., General Electric Co., Syracuse, N. Y.*

Mention No. 648 when filling out card.

Frequency Calibrator

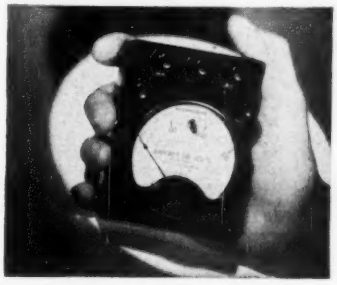
New "Model 111 crystal calibrator" was designed for frequency calibration in range of 250 kc. to 1000 Mc. Accuracy is 0.001 percent. Unit has self-

contained receiver with a sensitivity of 2 microwatts. A new circuit arrangement utilizes cross-modulation products of three separate oscillators operating at fundamental frequencies of 0.25, 1.0 and 10 Mc.—*Measurements Corp., Boonton, N. J.*

Mention No. 649 when filling out card.

Portable Electrical Instruments

New "P-12" line of portable electrical instruments, rated in two-percent-accuracy class, utilizes both moving-iron and permanent-magnet moving-coil mechanisms. Ammeters range

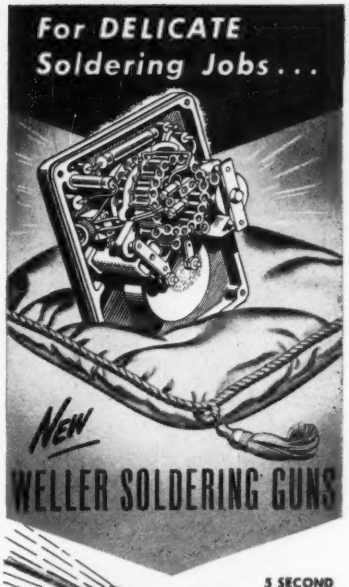


from 20 microamps. to 50 amp. d.c., and from 5 ma. to 50 amp. a.c. D-c. voltages range from 10 mv. to 800 v., with a-c. ranges from 1.5 to 300 v. Rectifier milliammeters range from 0.5 to 10 ma., and rectifier voltmeters from 2 to 800 v. All units are magnetically shielded.—*Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.*

Mention No. 650 when filling out card.

Feeder Voltage Regulators

New design and construction features of maker's "AFR" step feeder-voltage regulators are: in easier inspection of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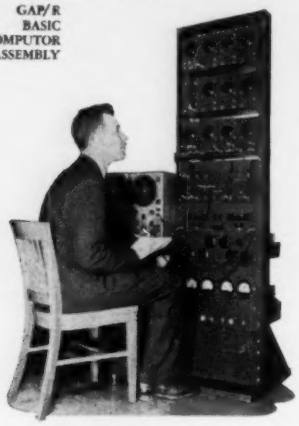

SPECIFICATIONS

Components: Regulated Power Supply, Central Chassis, Plug Panel, Rack and Accessories, 12 K3 Components (5 K3-C Coefficient Components, 3 K3-A Adding Components, 3 K3-J Integrating Components, 1 K3-L Unit-lag Component).
Excitation: Compound square-wave based on 0.004-second intervals. Connections provided for other forms of excitation.
Presentation: Recurrent solutions for all variables, via one or more oscilloscopes (not supplied), plotted against time or against one another.
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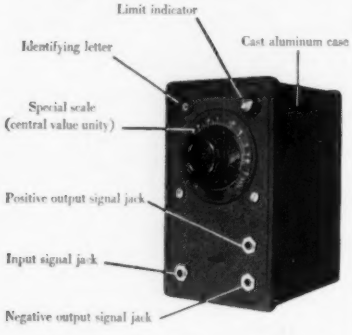

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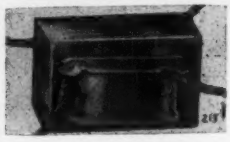
mechanism and transformer, improved bushing arrangement, synthetic-gasket seal, band-width adjustment, and synthetic flame-proof wire, along with several other improvements.—*Allis Chalmers Mfg. Co., 942 S. 70th St., Milwaukee, Wis.*

Mention No. 651 when filling out card.

Miniature Transformers

New "Type SSO" transformer's dimensions are 0.4 by 0.75 by 0.56 in.; weight 0.28 oz. Five stock types cover input, interstage, output and reactor



applications. Molded-nylon bobbin and non-hygroscopic insulation are used. Units are vacuum impregnated.—*United Transformer Co., 150 Varick St., New York 13, N. Y.*

Mention No. 652 when filling out card.

Timer Relays

New models of maker's timer-relays are improved not only through use of

specially prepared mercury but through a new ceramic which is little affected by mercury arc.—*Durakool, Inc., Elkhart, Ind.*

Mention No. 653 when filling out card.

Audible-signal Darkroom Timer

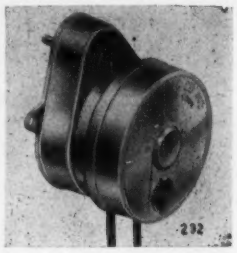
New "Type T-68" timer has a range of 0 to 40 minutes, and signals end of timing period with an electric buzzer. Contacts handle loads up to 1200 watts.

Grey-plastic case has mounting holes provided in back. Anodized-aluminum pointers are resistant to acid and alkali. Timer has automatic reset.—*General Electric Co., Schenectady 5, N. Y.*

Mention No. 654 when filling out card.

Timing Motors

New "4400 Series" timing motor is extra slow, available in standard speeds of 6, 8, 12 hours, 1 day and 1 week per

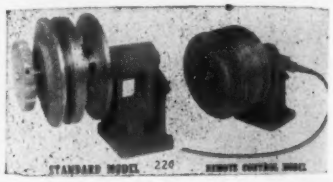


revolution. Non-standard speeds are available on quantity orders in ranges of 5, 9, 10, 15, 16, 30, 32 and 36 hours, and 2, 4, 10 and 30 days per revolution.—*Haydon Mfg. Co., Inc., Torrington, Conn.*

Mention No. 655 when filling out card.

Speed-control System

New "Fra-Sure" variable-speed transmissions consist of a double-grooved pulley on a floating type jack-shaft with one groove driven by motor



and other driving machine with two A-section V belts. Drives are for fractional-horsepower motors.—*Frazier & Sons, 338 Cortlandt St., Belleville, N.J.*

Mention No. 656 when filling out card.

Automatic Timer

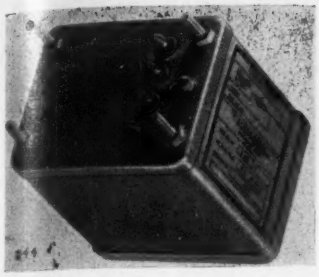
New "No. 86" double-pole timer is operated with spring-powered clock movement. It is supplied in timing ranges of 30 minutes, one hour, two,

and twelve hours. Contacts are rated at 15 amp., 125 v., and 10 amp., 250 v. with relay available for higher capacities.—*Walser Automatic Timer Corp., Graybar Bldg., New York 17, N. Y.*

Mention No. 657 when filling out card.

Hermetically-sealed Timers

New hermetically-sealed enclosures, now furnished for maker's timers, are evacuated to 100 microns and filled to one atmosphere with dry nitrogen so that full switch ratings can be used

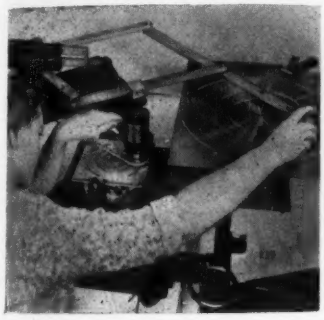


even at extremely high altitudes where contact capacity is normally reduced. Deterioration of motor brushes is said to be completely eliminated.—*A. W. Haydon Co., Waterbury, Conn.*

Mention No. 658 when filling out card.

Engraving Machines

New industrial engraving machines, especially designed for quick and easy operation by unskilled labor, work on tracer-guided principle whereby a grooved master template is traced and

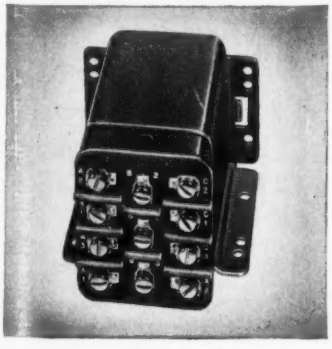


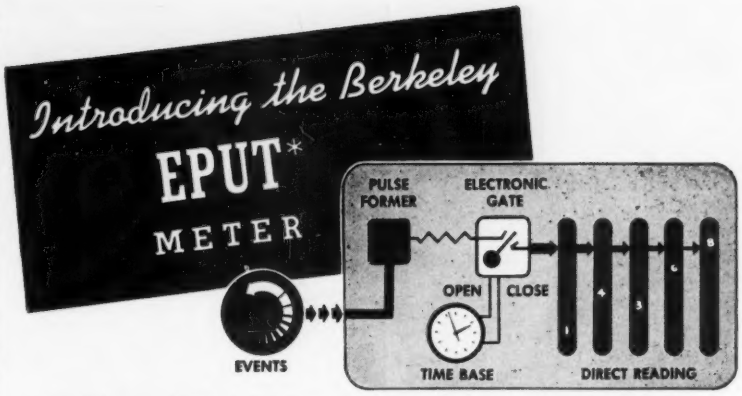
machine reproduces in many adjustable sizes any kind of design, wording, numerals, etc.; also suitable for interior contour milling, profiling, slotting, layout work, etc. It is claimed that engraving area covered in one set-up of new engraver is "larger than that covered by any other machine of its kind."—*New Hermes, Inc.*, 13-19 *University Place, New York 3, N. Y.*

Mention No. 659 when filling out card.

Hermetically-sealed Relays

New hermetically-sealed relays are available in four standard aluminum container types: Lug Header Type,





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Army-Navy Connector Type, Octal Plug Type, and Screw Terminal Type (illustrated); also in a wide variety of contact combinations and operating voltage ranges. It is said that through development of a new method of sealing, weight of new units is far less than those previously offered to industry. —*Guardian Elec. Mfg. Co.*, 1621 *W. Walnut St., Chicago* 12, *Ill.*

Mention No. 660 when filling out card.

Gamma-ray Detector

New "Model 939 Scintillometer" gamma ray detector employs scintillation principle, and provides a detection sensitivity over 100 times that obtainable by conventional portable Geiger

Counters. Instrument will operate continuously between -20 F. and 110 F., with a relative humidity of 95 percent. Unit is housed in a weather-proof aluminum-alloy case, 3.5 by 11 by 13 in. and is supplied complete with batteries, canvas carrying case and strap.—*Halross Instruments Corp., Ltd.*, 171 *Garry St., Winnipeg, Canada.*

Mention No. 661 when filling out card.

Light Sources for Photoelectric Relays

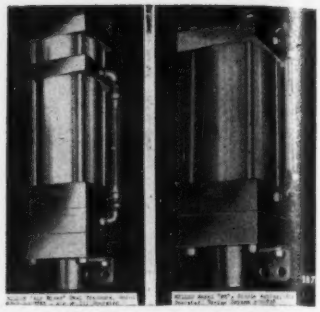
New light sources for photoelectric relays have snap covers for fast lamp

replacement. Lamps are prefocussed. Lens is 1.5 in. dia. Dimensions are 7 by 2.5 by 5 in.—*General Electric Co., Schenectady* 5, *N. Y.*

Mention No. 662 when filling out card.

Fluid-pressure Boosters

New line of fluid-pressure boosters have operating speeds from 30 to 450 strokes per minute. "Model B-2" illustrated on right is single-acting spring-return air-operated, and "Model B-4" (left) is double-acting air or oil-type that will save up to 95 percent of fluid used. Output pressures developed range up to 10,000 psi.—*Miller Motor Co.*, 4027 *N. Kedzie Ave., Chicago* 18, *Ill.*



Mention No. 663 when filling out card.

Adjusting Knob with Turn-counting Dial

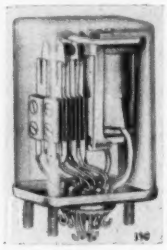
New "Microdial" is composed of two concentrically-mounted dials for counting turns up to ten and increments of each turn, giving indication to 1 part in 1000. Turn-counting dial speeds up

as incremental dial passes from one turn to next to eliminate confusion in readings close to integral turns. It also distinguishes between tenth turn and zero point. Dial requires 1.75 in. dia. of panel space.—*Gibbs Div., The George W. Borg Corp., Delavan, Wis.*

Mention No. 664 when filling out card.

Relay Assembly

New "MT" hermetically-sealed telephone type relay with steel enclosure measures 1 by 1.688 by 2.156 in. Dimensions of unhoused relay are 0.688 by 1.5 by 1.375 in. "M" enclosure, il-



lustrated, will accommodate relay with maximum contact stack and can be fitted with all headers except standard octal plug. "K" enclosure, not illustrated, will take any "MT" or maker's "KR" series with any header including standard octal plug. Hermetically-sealed relays are desiccated at high temperature and sealed in one atmosphere of nitrogen, eliminating

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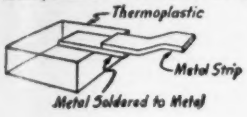

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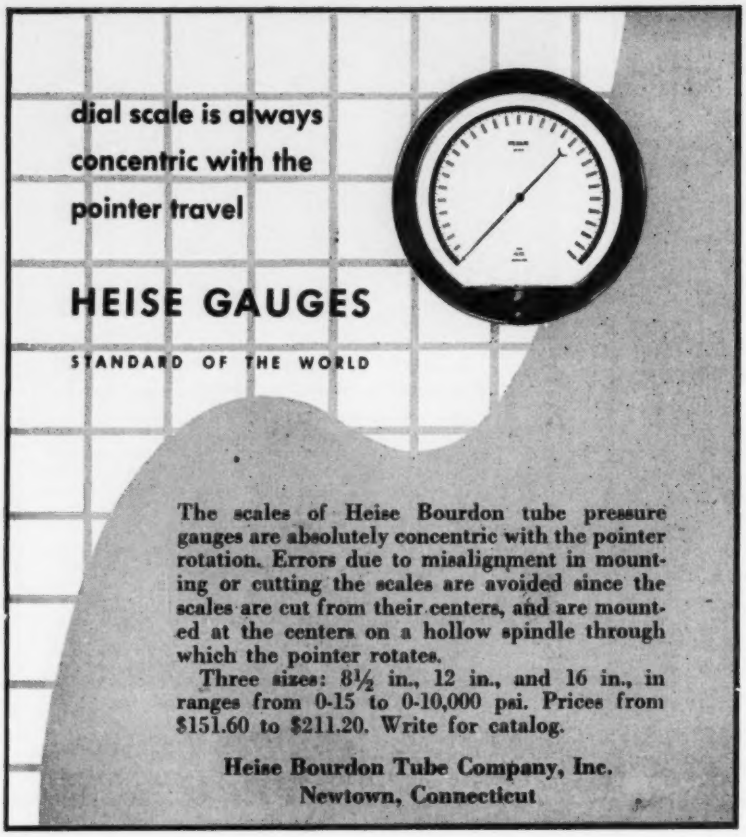
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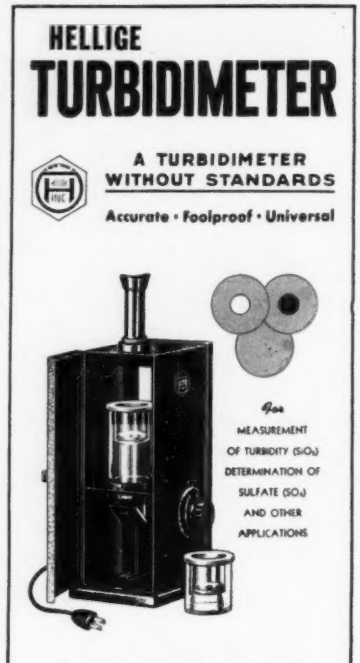
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oxidation and reducing contact arcing. Contacts are of any arrangement up to 16 springs (8 per stack) with a limit of six movable poles. Unit is available with windings from a fraction of an ohm to 22,000 ohms for operation up to 230 v. a.c. or d.c. Minimum operating power is 0.050 watts per pole. Maximum coil power for unenclosed unit is four watts.—*Potter & Brumfield, 265 N. Main St., Princeton, Indiana.*

Mention No. 665 when filling out card.

Sensitive Relay

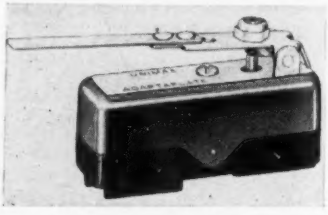
New sensitive relay operates when contact is made in any circuit having resistance up to 1 megohm. Maximum current through contact circuit is of

the order of microamperes. Contacts may be n-o., n-c., or both, and will handle up to 4 amps. depending on voltage and inductance. Relay may be furnished with seal and reset. Unit mounts on standard 4-in. electrical-connection box.—*Servo-Tek Products Co., 4 Godwin Ave., Paterson 1, N. J.*

Mention No. 666 when filling out card.

Precision Switch

New "Type MXT-1-Z131" leaf-actuated snap-acting precision switch has screw adjustment on actuator permit-



ting operating point to be set at exactly the correct position after installation.—*Unimax Switch Div., W. L. Maxson Corp., 460 W. 34th St., New York 1, N. Y.*

Mention No. 667 when filling out card.

CORRECTION

New "Dyna-Cath" apparatus (page 474 of our May issue). The manufacturers, Eberbach & Sons Co., Ann Arbor, Mich., call our attention to the fact that our brief description implied too much by using the term "polarographic analyzer." They remind us that the name "Polarograph" is a trademark name owned by E. H. Sargent Co. They point out that the "Dyna-Cath" is "a simpler apparatus designed for the separation of metals dissolved in an electrolyte."

JOURNAL of the Instrument Society of America

I.S.A. National Office, 921 Ridge Ave., Pittsburgh 12, Penna.

Vol. 6 JUNE, 1950 NO. 6

The Buffalo Instrument Exhibit

FOR WHAT specific purposes do instrument men and other interested and influential individuals visit the National Instrument Exhibits? We have accumulated definite data to answer this question. Following the St. Louis Exhibit, a questionnaire was sent to each individual who attended the Exhibit. Approximately 50 percent replied. An analysis of the replies showed that 40 percent attended for reasons of general interest, and to learn more about the instruments used in connection with their occupation. 24 percent attended to make a check-up on new instruments and developments in the field of instrumentation. 17 percent attended in search of particular information for the solution of a problem, and for comparison of the products of different manufacturers. That the visitors did obtain the answers and information that they came for, is shown by these percentages: 37 percent replied that they had received specific answers and information. 22 percent replied that they were partially satisfied with the answers they received. Only 2.1 percent replied that they had not received the information they came for. These are impressive figures.

Personal experience has of course proven to all who have attended National Instrument Exhibits that the week of the Exhibit offers the one great opportunity of the year for instrument men to learn more about their chosen field by seeing the new, by obtaining solutions to their problems, by trading opinions and experience and by renewing old friendships and finding new friends.

The all-out efforts made by the exhibiting manufacturers that resulted in making the above analysis of replies so satisfactory cannot be too highly praised.

Again in Buffalo this September many leading manufacturers will outdo themselves to display their instruments and accessories for study by the visitors. Their best engineers will be available to explain fully the applications and operations of the instruments exhibited and to answer questions.

It is worthy of note that at no previous Instrument Exhibit has a higher percentage of the available booth space been sold at such an early date. One hundred and fifty three booths have been reserved to date. Following is a list of the Buffalo Exhibitors.

Only twelve booths remain open. If you have a manufacturing friend who is not an exhibitor, bring this fact to his attention. With your help we will be able to announce in the next issue of the Journal that the Show is a SELL-OUT—no space open.

List of Exhibitors
As of May 25, 1950

COMPANY	BOOTH
Aircraft Marine Products, Inc.	413
American Institute of Elec. Engrs.	327
American Institute of Physics	108
American Instrument Co.	440, 442
American Meter Co.	511, 513, 515
Anders Co.	405
Annin Co.	219
Assembly Products, Inc.	222
Automatic Temperature Control Co.	331
Bacharach Industrial Instrument Co.	325
Baird Associates Inc.	225
The Baker Co.	324
Barber Colman Co.	414
Barton Instrument Co.	206
Beckman Inc., Arnold O.	234, 236, 238
Biddle Co., James G.	239
Brabender Corp.	316
Bridgeport Thermostat Div., Robertshaw Fulton Controls Co.	228
Brooks Rotameter Co.	423, 425
Brush Development Co.	415, 417
Buffalo Meter Co.	111
Burgess Battery Co.	318
Century Geophysical Corp.	118
Chemiquip Co.	436
Climax Control Div., Black, Sivalls & Bryson, Inc.	213, 215
Conoflow Corp.	439, 441
Consolidated Engineering Corp.	107, 109
Continental Equipment Co.	209, 211
Corry Instrument Co.	222
Cramer Co., R. W.	438
Daven Co.	328
Davis Instrument Div., Davis Emergency Equipment Co.	210
DeZurik Shower Co.	204
Diamond Power Specialty Co.	334
Eagle Signal Corp.	410
Electric Auto-Lite Co.	116
Emery Co., A. H.	336
Fischer & Porter Co.	101, 103, 105
Fisher Governor Co.	429, 431, 433
Fredric Flader, Inc.	416
Fulton Sylphon Div., Robertshaw Fulton Controls Co.	337, 339, 341
General Electric Co.	301, 303, 305
Giannini & Co., G. M.	338
Gotham Div., American Machine & Metals, Inc.	340, 342
Gow-Mac Co.	406
Hammel-Dahl Co.	501-503
Hankison Corp.	312
Haydon Co., A. W.	110
Hays Corp.	112, 114
Heise Bourdon Tube Co.	336
Helicoid Gage Div., American Chain & Cable Co.	411
Helipot Corp.	234, 236, 238
Hills McCanna Co.	137
Holtzer Cabot Electric Co.	309
Illinois Testing Labs., Inc.	237
Imperial Brass Mfg. Co.	223
Industrial Electronics Inc.	230
Industrial Instruments Inc.	310
Institute of Radio Engrs.	127
Instrument Development Labs.	412
Instruments Inc.	314
Instruments Publishing Co.	106
J-B-T Instruments Inc.	308
M. S. Jacobs & Assoc., Inc.	212, 214
Jerguson Gage & Valve Co.	241
Kay Electric Co.	404
Kieley & Mueller, Inc.	407, 409
Lapp Insulator Co.	427
Leslie Co.	122, 124
Magnetrol, Inc.	113
Marion Electrical Instrument Co.	240
Mason Neilan Regulator Co.	418, 420, 422
McAlear Mfg. Co.	207
Meriam Instrument Co.	315, 317
Milton Roy Co.	235
Mine Safety Appliances Co.	302, 304
Miniature Precision Bearings, Inc.	117
Moore Products Co.	435, 437
Nash Engineering Co.	401, 403
National Technical Labs.	234, 236, 238
Nestor Engineering Co.	324
New Hermes Engraving Mach. Corp.	224
Palmer Thermometers Inc.	319, 321
Panellit Inc.	201, 203, 205
Penberthy Injector Co.	430
Penn Industrial Instrument Corp.	221
Permutit Co.	226
Photoswitch Inc.	311, 313
Physicists Research Co.	121, 123, 125
Precision Thermometer & Inst. Co.	202
Proportioneers Inc.	218
R-S Products Corp.	419, 421
Rochester Mfg. Co.	424
Rockwell Mfg. Co.	408
Sanborn Co.	216
Servo Corp. of America	402
Shand & Jurs Co.	323
Sharples Corp.	509
Standard Electric Time Co.	335
Sticht Co., Inc., Herman H.	322
Streeter Amet Co.	320
Superior Tube Co.	115
Taber Instrument Corp.	326
Telechron Inc.	119
Trerice Co., H. O.	220
Trimount Instrument Co.	208
Uehling Instrument Co.	507
U. S. Gage Div., American Mach. & Metals Inc.	340, 342
Vapor Recovery Systems Co.	329
Veeder-Root, Inc.	505
Wallace & Tiernan Products, Inc.	307
Weatherhead Co.	330, 332
Welch Mfg. Co., W. M.	232
Welwyn Electronic Components, Inc.	306
Weston Electrical Instrument Co.	227, 229
Wheelco Instruments Co.	217
Yarnall Waring Co.	132

Central New York Section

On May 15 the ISA Executive Committee voted favorably on the charter application of the Central New York Section ISA. A most hearty welcome is extended to the members of this new group, the fifty-second such group to be granted a Section charter. Secretary of the Section is Mr. Karl W. Robertson, Minneapolis-Honeywell Reg. Co., 121 W. Onondaga St., Syracuse 2, N. Y.

UNIVERSITY OF MICHIGAN LIBRARIES

About Your Buffalo Hotel Reservations

If you plan to attend the Fifth National Instrument Conference and Exhibit to be held in the Memorial Auditorium in Buffalo from September 18 through the 22, 1950, and have not yet made your Hotel reservations, we urge you to consult the map and Hotel list shown on this page and make your reservations without delay.

It should be kept in mind that Buffalo is a Vacation City owing to its location on the Great Lakes and its proximity to Niagara Falls and Canada and that all hotels are generally filled to capacity during the period of the Exhibit.

Write directly to the Hotel of your choice and be sure to specify that you are visiting Buffalo to attend the Instrument Conference and Exhibit, and your requests will receive special consideration. For further information on accommodations write to the Buffalo Convention and Tourist Bureau, 602 Genesee Building, Buffalo 2, New York. Hotels recommended by the Bureau are:

HOTEL BUFFALO: Washington and Swan (map, 1) Tel: WA-4560. Singles $3.00 up; Doubles $5.50 up; Twins $6.50 up. Every room with bath, free radio and circulating ice water.

HOTEL GRAYSTONE: Johnson Park at Delaware Ave. (map, 2) Tel: CL-4700. Singles $2.25 up, connecting bath; with bath $3.00 up; Doubles $3.50 up, connecting bath; Twins $5.50 and $6.00.

HOTEL GENERAL BROCK: Niagara Falls, Ont. Singles $4.00 up; Doubles $6.00 up.

HOTEL LAFAYETTE: Washington and Clinton (map, 3) Tel: CL-5470. Singles $3.75 up; Doubles $6.50 up; Twins $7.00 up.

HOTEL LENOX: North near Delaware (map, 4) Tel: GR-1700. Singles $4.50 up; Doubles $7.00 up.

HOTEL MARKEEN: Main at Utica Sts. (map, 5) Tel: LI-8600. Singles $2.25 up; Doubles $4.00 up.

MIDTOWN HOTEL: 430 Delaware Ave. Tel: MO-2200. Singles $3.00 up; Doubles $5.00 up; Twins $7.00 up—all rooms with bath.

HOTEL RICHFORD: 210 Delaware Ave. (map, 6) Tel: MA-4300. Singles $2.25 up; Doubles $3.75 up; Twins $5.00 up.

THE SHERATON: 715 Delaware Ave. (map, 7) Tel: GR-2121. Singles $4.35 up; Doubles $5.85 up; Twins $6.85 up.

HOTEL STATLER: Delaware Ave. at Niagara Square (map, 8) Tel: MO-1000. Singles $4.00 up; Doubles $6.50 up; Twins $8.00 up. Every room with bath, radio and circulating ice water.

HOTEL STUYVESANT: 245 Elmwood Ave. (map, 9) Tel: GR-8020. Singles $4.50 up; Doubles $6.50 up; Suites $7.00 up.

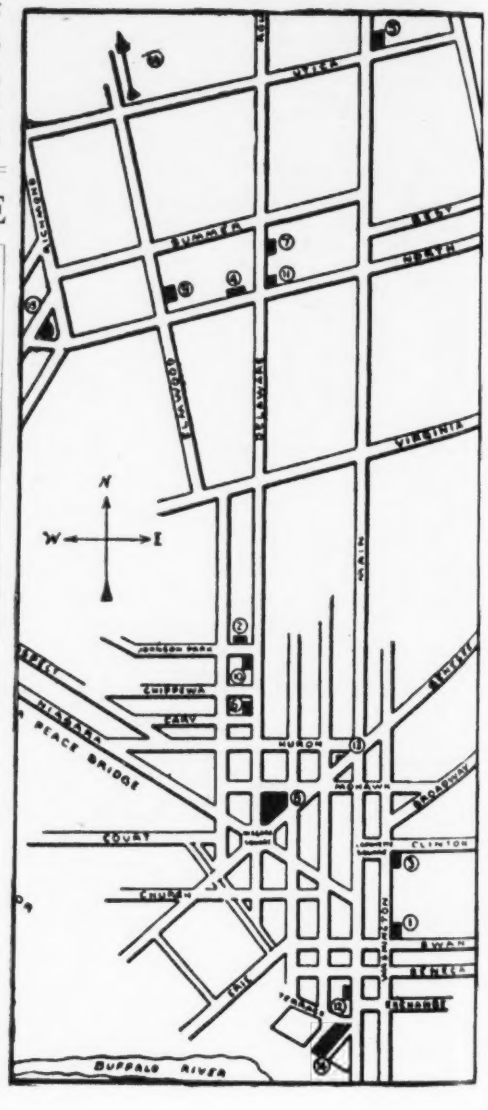
HOTEL TOURAINE: 274 Delaware Ave. (map, 10) Tel: WA-6500. Singles $3.00 up; Doubles $5.50 up; Twins $7.00 and $7.50; Suites $10.00 to $13.00.

HOTEL WESTBROOK: 675 Delaware Ave. (map, 11) Tel: GR-9100. Singles $5.00; Doubles $8.00.

HOTEL WORTH: 200 Main St. (map, 12) Tel: CL-0111. Singles $2.00 up; Doubles $3.25 up.

Buffalo Hotels and Convention Hall Map Legend

1—Hotel Buffalo
2—Hotel Graystone
3—Hotel Lafayette
4—Hotel Lenox
5—Hotel Markeen
6—Hotel Richford
7—The Sheraton
8—Hotel Statler
9—Hotel Stuyvesant
10—Hotel Touraine
11—Hotel Westbrook
12—Hotel Worth
13—Buffalo Convention and Tourist Bureau
14—Memorial Auditorium
16—New York State Institute of Applied Arts & Sciences 1685 Elmwood Ave.



LETTER OF WELCOME

BUFFALO
Everything for a Successful Convention
CONVENTION AND TOURIST BUREAU, INC...602 GENESEE BUILDING

May 5, 1950

The Instrument Society of America
921 Ridge Avenue
Pittsburgh 12
Pennsylvania

Gentlemen:

Buffalo bids a most cordial welcome to the 5th National Instrument Conference and Exhibit. We are grateful and happy that you have honored us by selecting our city for this conference and we will endeavor, in every way, to make your stay here both pleasant and profitable.

Buffalo promises you a never-to-be-forgotten visit. Not too large, not too small, this City of Good Neighbors will give you more than mere convention sessions in a hotel. It will provide entertainment, recreation, and sight-seeing possibilities unequaled in the world. Here is the gateway to Canada--hydro-electric power capital of the world--leader of diversified industry--city of homes and beautiful trees--threshhold of Niagara Falls--flour milling king--aircraft manufacturing center and convention city beyond compare.

Come to Buffalo and be welcome. The friendly neighbors here will be delighted to greet you.

Sincerely yours,
Ward Stewart
H. Ward Stewart, Jr.
Secretary - Manager

HWS/ad

ISA EMPLOYMENT SERVICE

Forward your letter to INSTRUMENT SOCIETY OF AMERICA, 921 Ridge Ave., Pittsburgh 12, Pa.

SALES ENGINEER. By large manufacturer of valves, gages, industrial instruments to be connected with Chicago District Office. Should have sales engineering experience on pressure and temperature instruments, potentiometers, pyrometers, etc. Must have automobile. Salary and expenses. State education, experience and salaries earned in first letter. All applications held confidential. Location Chicago. Box 300.

INSTRUMENT SALES MAN. Boston Territory. Must have successful sales record for pressure and temperature instruments. Leading manufacturer. Salary and expenses. State experience, education and salaries earned. Replies confidential. Box 301.

INDUSTRIAL INSTRUMENT AGENTS. An old established medium sized manufacturer with complete line industrial thermometers, recorders, controllers, dials and self-ops will consider allocating agency territories to well established and qualified representative. Box 302.

INSTRUMENT DESIGN ENGINEER. For Atomic Power. Must have at least a BS in electrical engineering and in addition have several years practical experience in the development and design of instrumentation and servomechanisms. A thorough knowledge of electronic regulating systems, amplifiers and simulators is also a requirement. The work is related to the development of regulating devices and instrumentation for control of nuclear power plant. Location, suburb of Pittsburgh, Pa. Write for application. Box 303.

VALVE AND INSTRUMENT APPLICATION DESIGN ENGINEER. Combination sales and design position. Successful applicant should be an engineering graduate with a special spark for process and power valving and instrumentation. Should have ten years experience in this field. A substantial old midwestern manufacturer offers a fine future for a man having real talent. Salary $6500 with bonus for outstanding performance. Location Cincinnati, Ohio. Box 304.

DESIGN DRAFTSMAN. For product design on electromechanical and pneumatic devices for process control. Must have four years of technical schooling or equivalent and two to four years experience in small mechanisms of the above nature, industrial instruments preferred. Should have at least 8 years drafting experience and be familiar with modern material and methods and manufacturing practices. Furnish particulars, age, experience and salary requirements. Location Philadelphia. Box 305.

MANUFACTURERS' AGENTS. For established line of recorders, controllers for pressure, temperature, time and humidity. Exclusive territories available for some areas. Non-exclusive distributorship on complete line including industrial and dial type thermometers and pressure gages. Box 306.

RESEARCH PERSONNEL. Require key men for research laboratories. Outstanding opportunities now available in undertaking highly responsible research acid development work in important electromechanical instrumentation laboratories. Require section chiefs with M. S. or Ph.D. degree in E.E., M.E., or Physics with scholastic achievement in upper 10 percent of class. Important to have more than 5 years practical experience in development work, supervision of projects or group activities to qualify applicant to supervise and direct several diversified projects and administer related activities. Men with proven ingenuity, imagination, creative ability and with a record of tangible accomplishments can command attractive salaries. Location Chicago. Box 307.

MECHANICAL DESIGNER. Mechanical Engineering graduate having several years experience in design and development of mechanical and electromechanical instruments. Location Rochester, N. Y. Box 308.

DISTRICT MANAGER for Los Angeles sales office of Philadelphia manufacturer specializing in pneumatic force-balance process control instruments. Write fully, stating salary desired, education and experience. Replies held confidential. Box 309.

ELECTRICIAN, METERS. Install, test, calibrate, maintain and repair ammeters, voltmeters, wattmeters and other electric meters of a wide variety of sizes and types including indicating, integrating and graphic. Work from complex wiring diagrams and control circuits and panels for electric furnaces, turbogenerators and other power plant equipment. Knowledge of routine test procedure for steam flow, air flow, combustion control, pressure and temperature instruments. Day shift at Alloy, W. Va. for Electro Metallurgical Div. of U. C. & C. Corp. Three months probation period. Start at $1.73 per hour, advance to full job rate in steps of five cents every month for a maximum period of three months. Box 310.

INSTRUMENT SALES REPRESENTATIVE by well known manufacturer of manometers, flow meters, tank gages, etc. for Southwest states. Interesting Commission. Box 311.

ISA Section Publications

CONTINUING the project of publicizing ISA local Section magazines, which was begun in the February issue of the Journal with an article on five Section magazines, we are reviewing below two additional publications, that of the New York and that of the Washington Section.

Both publications pictured below are reproduced on 8.5 by 11 in. paper folded lengthwise. Both are published monthly except during June, July and August, and each was developed from and replaces a meeting notice. The New York Section paper is reproduced by the offset process on white, while the Washington Section News is printed on a heavy yellow stock. Both papers consistently appear in the format as seen above.

The Washington paper first appeared in February of 1950 and each issue to date has been four pages. The New York sheet has appeared since September of 1949 and runs from four to eight pages. It has a circulation of 350 with 100 copies going to non-members. The Washington Section paper is distributed to about 500 persons (about 4 times the number of members in the Section) and is mailed out 10 days before meeting time.

Three men, Norman J. Cherry, Ralph R. Batcher and Charles E. Haggerty form the staff of the New York paper. R. G. Quick and H. W. Semon put out the Washington News.

Both publications give complete details on coming meetings. The New York paper goes into considerable valuable detail on speaker and subject. Both run lists of Section officers and publish the names of new members. The New York Section has found its publication to be an excellent medium for announcing and reporting on the Section Annual Regional Conference. A photograph taken at the 1950 conference dinner occupied two pages of the February issue. Both papers publish information on Section business and policy and announce events of National importance.

The Washington Section News regularly runs three departments: "The President's Page," "Stuff & Things from the Editor" and "Technical Tidbits." Titles of articles which have appeared include: "Members Invited to Help Run Section," "New Section Activities Proposed" and "Navy Instrument School Interested in ISA." The editorial policy of the Washington paper is based on an attempt to keep the reader informed about the doings of the Section and the Society in a way that is as pleasant as possible. Quips are used as fill-ins and humorous letters allegedly written to the editor appear. The editors feel that the paper has served to considerably arouse interest in the Society. Three issues examined contained a total of about 5000 words.

The Washington Section has plans in the making for running advertising in its paper. As can be seen above, the New York Section has already used the back cover of its magazine for ads. Eight ads, each 2.75 by 2.125 in. regularly appear here. Preferential space is given to Section members. The ads are accepted on a yearly basis, the same ads appearing in each of the 9 issues throughout the year. Each ad remains the same, no change in copy from month to month being acceptable. Plans are being made to expand this advertising to 3 pages.

There is little doubt that these two papers perform a very real service to members and are a definite integrating force in the Section and the Society.

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The Differential Transformer

As Applied to the Measurement of Substantially Straight Line Motions*

By W. D. MAC GEORGE†

Introduction

The measurement of substantially straight line motions is an important factor in the science of Instrumentation. For example, the measurement of the displacement of a bellows or a diaphragm, the motion of a float, the tip travel of a Bourdon tube and the tilt of a weigh beam.

Various means have been devised for converting these displacements into signals suitable for electrical transmission, but only in recent years has the differential been used to any extent in this field.

It is the purpose of this paper to treat with only two general phases of this topic:

1. The basic design of differential transformers; and.
2. The circuits which permit their application to the measurement of instrumentation variable such as pressure, flow, force, etc.

Although some of the structures to be described could easily be adapted to the measurement of rotary motions, these adaptations will not be discussed.

Part 1

A differential transformer consists essentially of a primary coil, two secondary coils and an armature of magnetic material. The primary coil is energized from a suitable source of alternating current, the two secondary coils are connected so that their output voltages are 180 degrees out of phase and the armature is located so that it can alter the relative flux distribution which exists between the primary coil and the two secondary coils. (See Fig. 1). Motion of the armature A toward secondary coil S1 results in an increased output of one phase and motion of A toward S2 results in an increased output of the opposite phase. If S1 and S2 are identical coils and A is located so that each receives an equal amount of flux, the voltages induced in these secondary coils will be equal and out of phase and a theoretical output of zero will result. This condition denotes the null, or balance point of the differential transformer.

Obviously, the electrical energy could be applied to coils S1 and S2 and the differential output obtained from coil P without basically altering the transformer structure or the results obtainable. This has been done in some designs.

In accordance with the previous descriptive data, the differential transformer becomes essentially a self contained device for producing an electrical output, isolated from the source of power, which may be controlled in both amplitude and phase by an adjustment of the flux distribution within the transformer. It should never be considered as part of a bridge circuit, but only as an isolated source of controlled alternating current.

A wide variety of differential transformer designs have appeared in patents and various publications during the last 50 years. Among these is the force balance device disclosed by Porter and Currier in 1905 and shown in Fig. 2. Although not intended for use as a differential transformer measuring device it has all the essential elements of the one shown in Fig. 1. Many designs utilize core structures of magnetic material such as the "E" and "H" core arrangements shown in Figs. 3, 4, 5, and 6. In one of these the armature A moves parallel to the pole pieces, in another it rocks about the center pole, etc.

The sensitivity of these magnetic core designs is very high but their output is definitely non-linear and the magnetic pull which exists between their armatures and their pole pieces can be an appreciable factor in many applications.

In view of these disadvantages, and keeping in mind that modern electronic circuits do not require large input voltages to successfully operate servo mechanisms, the differential transformers ideally suited to general instrumentation are of the air core type (Fig. 1). In units of this type, the armature is the only magnetic material in the entire structure and is responsible for the distribution of flux throughout the coils.

Of similar principle to the structure shown in Fig. 1, but of different geometry, are the two designs shown in Figs. 7 and 8 and attributed to Quereau and Hornfeck. In these designs the secondary coils lie either inside or outside the primary coil instead of at either end of it.

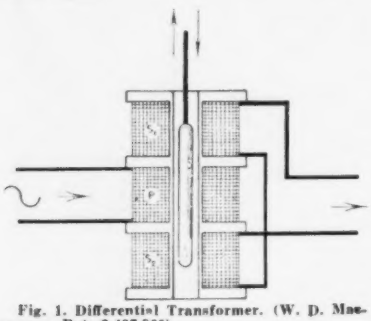


Fig. 1. Differential Transformer. (W. D. Macgeorge, Pat. 2,427,866)

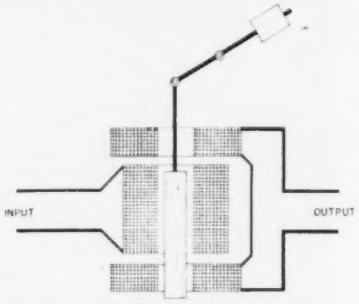


Fig. 2. Differential Transformer. (Porter and Currier, Pat. 808,944)

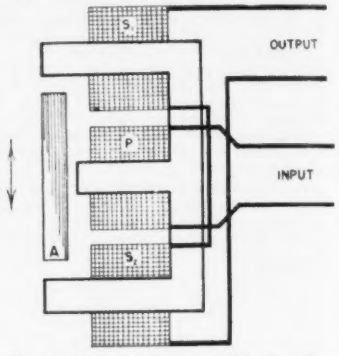
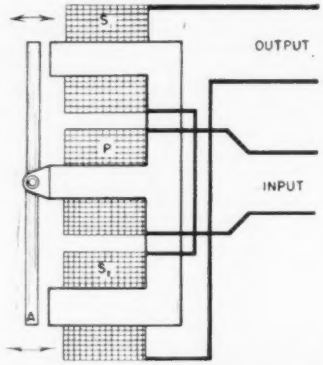


Fig. 3. "E" Core Differential Transformer (R. Mestas, Pat. 2,408,524)



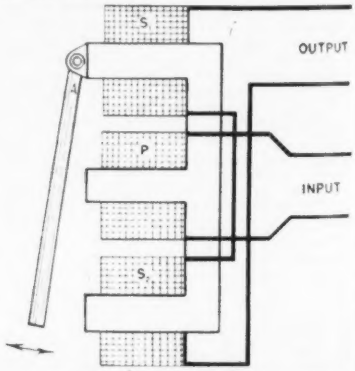


Fig. 4 and 5. "E" Core Differential Transformer. (Electronic Control Handbook by Batcher and Moulic)

* Presented at the Fourth Annual Conference of the Instrument Society of America, Sept. 14-16, 1949, St. Louis, Mo.

† Director of Research, Automatic Temperature Control Co., Phila. 44, Pa.

Note:—Statements and opinions advanced in papers are to be understood as individual expressions of the authors and not those of the Society.

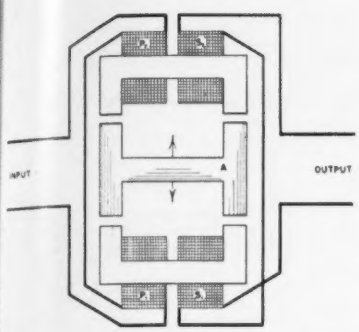


Fig. 6. "H" Core Differential Transformer. (P. Clingman, Pat. 2,353,691)

Investigation over a period of years and numerous field tests have led to a design which combines the desirable features of a differential transformer into a structure which can be reproduced accurately. This device is shown in Fig. 9. The coil structure, divided into two main sections, contains four windings, two of which serve as the primary while the remaining two act as the secondary. The small section at the left end of the coil form is used to house the necessary interconnections and lead wire terminations.

A design of the type shown in Fig. 9 insures equal and stable electrostatic coupling between the primary and secondary windings and minimizes temperature drift due to changes in such coupling. Uniform magnetic coupling is also insured on this same basis and this factor makes it possible to maintain reasonable linearity without a large number of turns. This in turn means that a coil of relatively low impedance can be produced which will adequately match into standard audio frequency transformers and allow the use of relatively long transmission lines without danger from stray pick-up and phase shift due to line capacity.

A coil structure of this type is also quite versatile. Although the unit is normally used with the primary coils connected series aiding and the secondary coils connected series bucking, this condition may be completely reversed, or the primary coils may be connected parallel aiding and the secondary coils parellel bucking, etc. Also, since the unit is essentially a two coil balanced structure, it is quite possible to bring out a center tap between the two adjacent windings and use one section as an induction bridge. Obviously there is an almost endless list of workable combinations when one considers that more than two windings can be placed in each section.

Some advantages inherent in a well designed differential transformer are:

1. Negligible phase shift throughout the operating range. In inductance bridge circuits the resistance of the coils remains constant while the inductance of these coils varies over a considerable range. The resulting shift in the resistance and inductance vectors causes a very substantial phase shift which must be taken into consideration in the design of any indicating circuits. In a differential transformer such as the "Atcotran"*, the change in inductance for an armature motion of plus or minus 0.1 inch (twice the normal range) is entirely negligible. Therefore, servo mechanisms operating with these transformers need not be compensated for phase shift throughout the indicating range.

2. The source of power is isolated from the output circuit. This feature allows units to be combined in various ways and to perform many useful mathematical functions.

*Trade mark registered. A.T.C. Co., Inc.

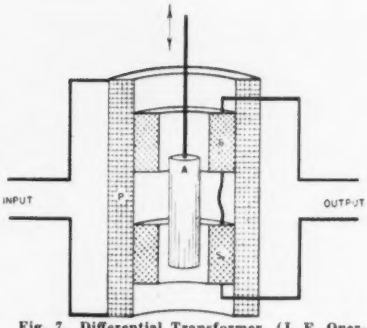


Fig. 7. Differential Transformer. (J. F. Quereau Etal, Pat. 2,050,629)

3. A high degree of linearity and reproducibility of output with respect to armature displacement is obtainable. A linearity, of better than plus or minus 0.05 percent may be expected from standard production run "Atcotrans" and these units will match each other within 0.5 percent without the use of calibrating resistors, or other means of compensating for normal irregularities in materials and in winding.

Approximate, detailed characteristics of the "Atcotran" type of differential transformer are:

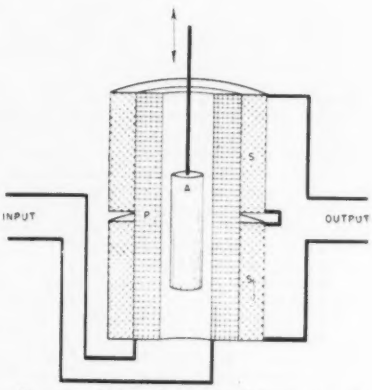


Fig. 8. Differential Transformer. (A. J. Hornfeck, Pat. 2,439,891)

null position is less than 0.01 grams. This force drops to zero at the null position.

5. For the frequency characteristics of the "Atcotran" see Figure 10. Note that the output of these transformers increases in a nearly linear manner with relation to frequency between 25 and 500 cps. and that a reasonance condition with a very high voltage output is approached

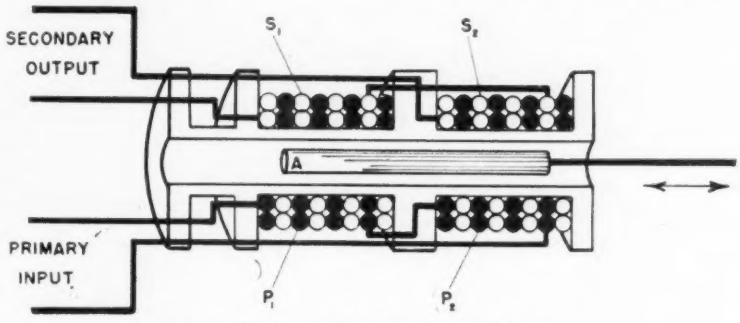


Fig. 9. "Atcotran" Type Differential Transformer.

1. D-c. resistance of both the primary and secondary coils is 22 ohms.

2. Inductance (with armature in the coil) of the primary coil is 12 millihenrys and 5.2 millihenrys for the secondary coil. the primary coils were connected aiding and the secondary coils were connected bucking for this check.

3. Linear range is plus or minus 0.15 inches.

4. Magnetic pull on the armature at a distance of 0.05 inches away from the center, or at 10,000 cps. This same curve also indicates the quality of the null balance point with respect to frequency. This voltage remains below 0.001 volts up to 5000 cps. and never goes above 0.0017 volts.

6. Transformer Output: (a) No step-up transformer—0.00025 volts/ volt input/ 0.001 inch of armature displacement. (b) 12:1 step-up transformer—0.00296 volts/volt input/.001 inch of armature displacement. (c) 22:1 step-up trans-

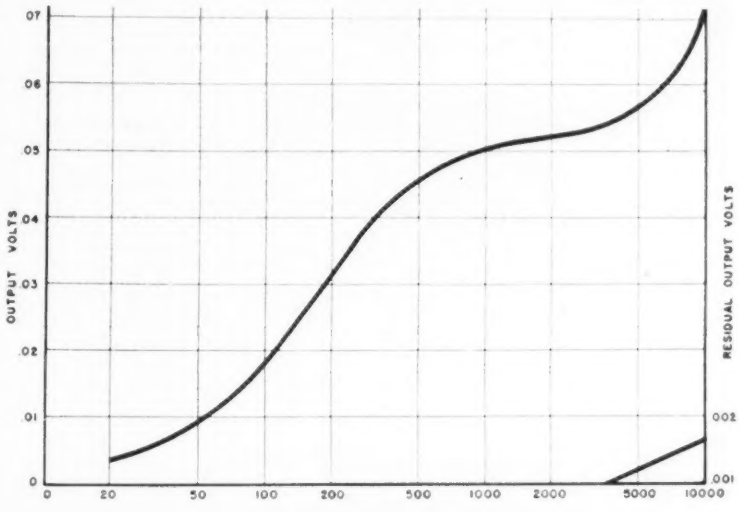


Fig. 10. "Atcotran" Frequency Response Curve.

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former—0.0052 volts/volt input/0.001 inch of armature displacement. (d) 0.0001 volts, or less output at balance with a 3.2 volt, 60 cps. input.

For comparison let us assume a single bonded type strain gage, connected into a bridge circuit and strained to approximately 0.003 inches per inch (about 100,000 psi, stress in steel); it would yield an output of 0.0015 volts/ volt input for this range. A differential transformer over its normal maximum range of 0.300 inches would yield an output of 0.075 volts, or an output advantage of 50:1 on a range basis of comparison.

It should be noted here that coils having a higher impedance than the unit just described would have considerably more output for a given displacement, but when used with the step-up, input transformer of an amplifier, this gain becomes a loss if the two transformers are not properly matched. For example, a transformer of the type shown in Fig. 1 with a secondary impedance of approximately 800 ohms will give the following results when used with the same step-up transformer as the "Atcotran" previously described:

1. No step-up transformer—0.00078 v/v. in /0.001 in. of Armature displacement.

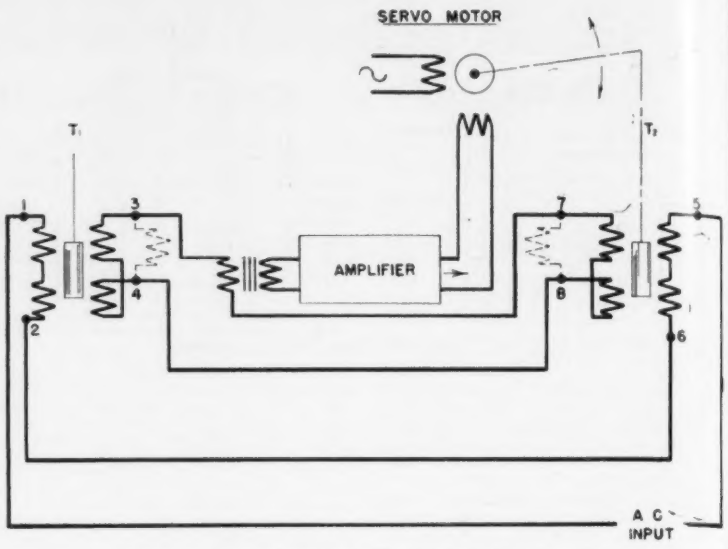

Fig. 11. Null Balance Circuit for Differential Transformers.

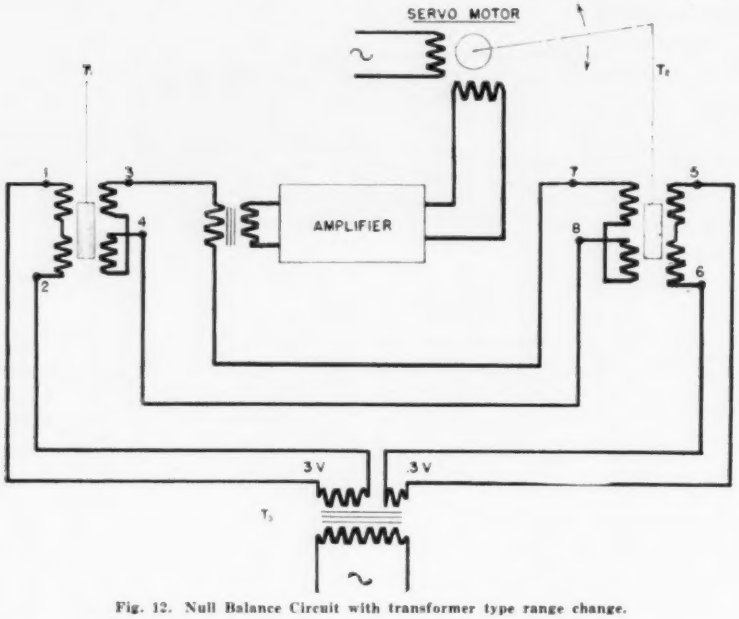

Fig. 12. Null Balance Circuit with transformer type range change.

2. 12:1 step-up transformer—0.00190 v/v. in/0.001 in. of Armature displacement.

3. 22:1 step-up transformer—0.00110 v/v. in/0.001 in. of Armature displacement.

It can be seen here that for use with a standard electronic component such as a line to grid transformer having a 50 to 200 ohm input impedance, the low impedance differential transformer is considerably superior to the 800 ohm variety. This same feature also makes it possible to capacitively shunt the input and output circuits of an "Atcotran" without serious effects. Ten microfarads connected across the terminals of such a differential transformer will not injure the operation of a null balance servo system.

Armatures for use with differential transformers may be made from a large variety of magnetic materials if a low null signal and reproducibility are not important (the author recalls using nails for his original tests), but when these items are important, the design of the armature should be done with care.

A magnetic steel having closely controlled properties, and properly stress relieved after any machining operation, will be adequate for most applications. Certain bonded ferrite structures in which the magnetic particles are held together by a bonding material which insulates the particles and is in itself quite stable, seem desirable from a production point of view.

With steel, if a cylindrical armature is used, this cylinder must be slotted along its major axis to limit eddy currents. These currents have a considerable effect on the null balance of differential transformers. Internal stresses in the material caused by machining, will seriously effect the balance of a transformer by causing a slight shift in the phase of one secondary coil with respect to the other. This condition must be given careful consideration at all times and can also be caused by large masses of aluminum, copper, brass or other non-magnetic materials located close to the differential transformer. In general, it is recommended that such masses be kept at least 0.75

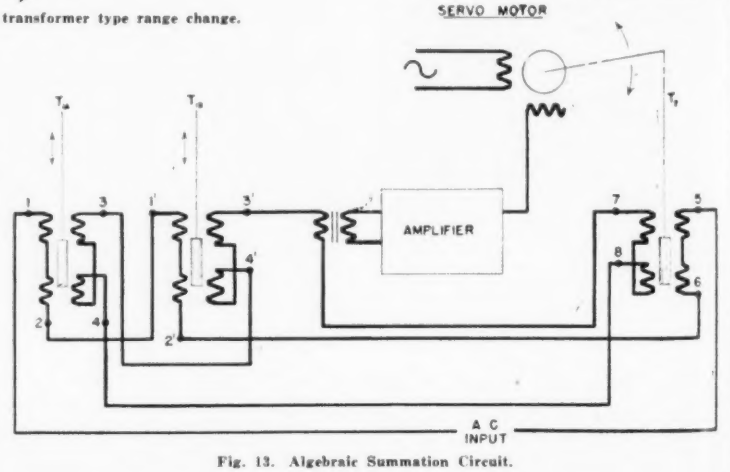

Fig. 13. Algebraic Summation Circuit.

inch away from the ends of the unit and that magnetic materials should maintain a clearance of twice this amount. Since the magnetic field of a differential transformer is elongated to give the required linearity, these units are much more sensitive to end effects than to side effects.

Part II

To apply the differential transformer to a measuring problem a null type of circuit is recommended. (See Fig. 11). In this circuit the output from the transmitting unit, T1, is 180 degrees out of phase with that of the balancing transformer, T2, and the difference voltage is fed through an amplifier to one phase of a two phase servo motor. The other phase of this motor is energized continuously from the line.

When both differential transformers are producing equal out-of-phase voltages, there will be no input to the amplifier and the motor will be at rest.

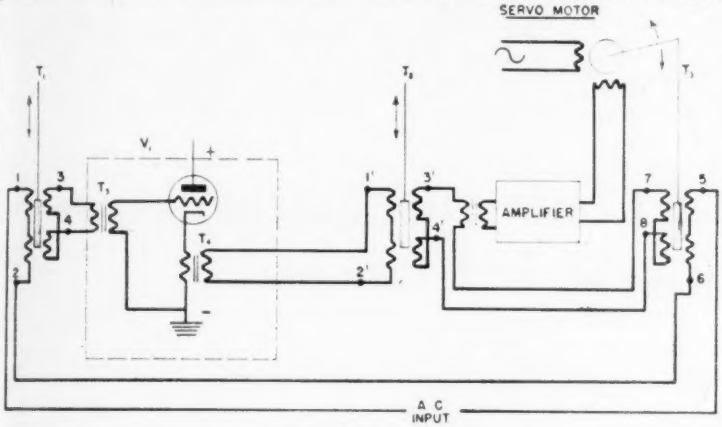

Fig. 14. Multiplying Circuit.

However, if the armature or transformer is displaced slightly, a restoring signal will be produced which will cause the motor to rotate and return the system to balance.

The reasons for using a null balance system are:

1. It is unaffected by line voltage changes. If there is no stray 60-cycle pick-up in the system it will be unaffected by normal line voltage changes and even an excessive pick-up voltage equal to 10 percent of the total signal at full scale, would only cause a 1 percent change in reading for a 10 percent change in line voltage. In normal systems the pick-up voltage will always be less than 1 percent of the full scale signal.

2. It is relatively unaffected by resistance changes in the connecting leads. The addition of resistance to either the primary or secondary circuit will have little effect on the balance of the circuit; although its sensitivity will be affected. This means that changes in coil resistance due to heating will not unbalance the circuit.

The following information may be of value in the application of null balance circuits:

Electrical zero check. If a shunt is connected across terminals 3 and 4 of the transmitting differential transformer (See Fig. 11), its output will be zero and the servo system will come to balance at the null position of the balancing differential transformer. This is a convenient method for checking the "zero" of the entire servo system. In general, it is desirable to have this point coincide with the true zero of the indicating system, but, under certain conditions, a center scale check point may have an advantage. Such an arrangement limits the travel of the armature to an equal distance either side of the null point and keeps it within the most linear portion of the differential transformer characteristics. On the other hand, the first method described, reduces the effect of stray pick-up in the system and permits the use of a very simple method of range change.

Electrical Range Change (Ratio control). If a resistor is connected across terminals 7 and 8 of the balancing transformer, T2, (See Fig. 11) its output will be reduced. This is true because the air core type of differential transformer has very poor regulation and its output will reflect any change in loading. When the output of T2 has been reduced in this manner, the servo motor will now have to move farther to balance a given change in input voltage from the transmitter and the effective sensitivity of the servomechanism will have been increased.

This method has been successfully used for sensitivity ratios up to 10:1 and may also be used as a calibrating means. A shunt resistor having a resistance of about 100 times that of the differential transformer secondary coil impedance, will reduce its output by 1 percent. If this shunt is placed across the transmitting unit, the sensitivity of the system will be reduced 1 percent, but if it is placed across the balancing unit the sensitivity of the system will be increased 1 percent.

In using shunt resistors for range changing and calibration it should be kept in mind that the desired ratio will only be maintained as long as the coil resistance and the shunt resistance maintain the same relationship. Temperature changes in the coil, unless properly compensated for, will upset this relationship.

It is possible to obtain similar results by means of transformers instead of by means of shunts (See Fig. 12). Here the input voltages to the two differential transformers are set up as a predetermined ratio by the supply transformer, T3. Ratios as high as 40 to 1 have been used with a circuit of this type. Its major draw back is the fact that changes in lead resistance affect the ratio to a certain extent.

Algebraic Summation (See Fig. 13). The use of more than one differential transformer as a transmitter is both feasible and useful. When transformers T1a and T1b are properly connected, their outputs are algebraically summated in such a way that their output voltages represent the magnitude to be measured and their phase becomes the plus and minus sign for this magnitude. The servo mechanism balances out the resulting signal and indicates the algebraic sum of the two variables controlling transformers T1a and T1b. Up to six transmitters have been successfully summated by this method without difficulty. A typical application is the use of four "Atcotran" load cells to support a weighing platform and a weighing servo to indicate the average signal from these cells. In this way the weighing platform becomes independent of load position.

Multiplication: If the input of one differential transformer is used as a source of input voltage for a second differential transformer, multiplication results. Since adequate power is not available in one transformer to drive another, the use of an electronic amplifier is recommended (See Fig. 14).

The output of T1 is stepped up by input transformer T3 and applied to the grid of a high transconductance cathode follower stage, V1. The output of this stage is transformer coupled by T4 to the input circuit of differential transformer T2. For example, assume that the output of T1 is 0.05 volts and the step-up ration of T3 is 20 to 1, then the grid input to V1 will be 1 volt and, if T4 has the proper ratio, this 1 volt will also appear across the input terminals of T2. If the output of T1 doubles, then the input to T2 doubles and since its output is proportional to its input the signal output of T2 will also double and is therefore effectively multiplied by two.

The differential transformer signal injected into the primary of T2 may be 100 percent of the total signal or only part of it. If this maximum signal should only be 20 percent of the total input to T2, its output would only change 20 percent of its immediate value for a change of from zero to 100 percent in the output of T1. This device has been used for compensating the output of a flow meter for changes in pressures and for other similar uses.

Use of Null Balance Circuits. In making connections between the various components of differential transformer null balance circuits, the author has standarized on the following procedures:

1. Use of twisted pairs for all primary circuits.

2. Use of shielded, twisted pairs for all secondary circuits, for runs over 50 feet.

3. Number 20 BS gage, stranded wire is of ample size for most installations. The wires should be run in conduit, but never in the same conduit with power lines.

If properly installed, transmitters and receivers may be several thousand feet apart.

Special 400 cycle systems requiring only a 50 *millivolt input* signal to the transmitter have been used for hazardous locations.

Although the differential transformer is still a newcomer in the instrument field, there are some standard instruments available (See Figs. 15 and 16). These include circular scale indicators with 0.25 percent of reading accuracy (above 10 percent of scale) and a ten to one sensitivity switch: multi-channel optical indicators with three automatically selected scales, a scale length of about 88 inches and a two-second speed of response; strip chart, round chart

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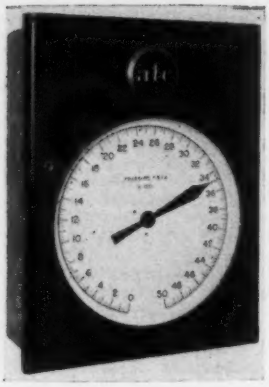

Fig. 15. Round-scale "Atcotran" Indicator.

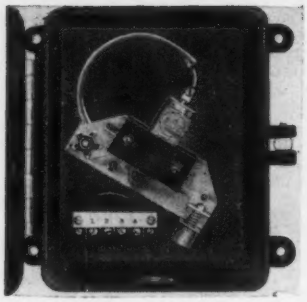

Fig. 16. Multi-channel "Atcotran" Indicator.

Fig. 17. "Atcotran" Pressure Transmitter.

single and multi-point recorders, controllers, etc. The switching of various input circuits into one indicator, or recorder, such as is normally done with thermocouple circuits, is standard practice with most differential transformer instruments. Transmitters, for pressure, flow, density, level, motion, etc., are also available as either standard, or custom built devices. Fig. 17 shows a Bourdon tube type of pressure transmitter.

While it is obvious that a direct indicating, meter type of instrument may be used with a differential transformer instead of a servo driven, null-balance device, no time will be devoted to these units at this time. It is only with the null balance systems that the remarkable accuracy and stability of the differential transformer can be realized.

In general, differential transformer instrument systems should be used.

1. whenever highly accurate measurements of motions are required,

2. where minute forces are available and friction of any kind would be a disadvantage

3. where electrical transmission of various variables is a requisite and

4. where it is desired to express certain mathematical functions electrically.

Application Of Computing Mechanisms To Industrial Instruments*

By M. J. BOHO†

THE TITLE of our article sounds perhaps more formidable than is its contents. Every one is familiar with the present-day gas station pumps which not only meter the flow of gas to our automobile tanks but also multiply the gallons by the price per gallon. The result of this operation is both the number of gallons sold and the amount of money poured into the tanks. It should not seem too difficult to the instrument engineers to see that similar computations made in industrial processes might achieve similar results and benefits. One of the principal benefits would seem to be the ability to go directly to a record of the variable of real interest, thus eliminating all of the laborious steps of calculation, with their opportunities for mistakes, which have seemed to us up to now a natural way of obtaining the desired answers.

Such computing instruments are already in successful use in many plants performing such jobs as recording the rate of heat and energy flow, recording one component of a mixed flow, automatically correcting meter readings for line density variations, and others. As this type of instrumentation is growing in use, it is the purpose of this article to show some of the basic instruments and mechanisms which are being applied successfully to this type of problem.

Two recent Hagan Ring Balance meter developments go a long way to make computing instrumentation practical for the industrial meter field. The first of these is the dual meter, shown in Fig. 1, which consists essentially of two separate meters in the same housing arranged to record on a single chart and so designed that the meter deflections can be combined. The second is a development of a line of coupling linkages to effect the desired combination.

These linkages are of two basic types. The additive coupling, shown in Fig. 2, is designed to produce an output displacement which is either the sum or difference of two inputs. The multiplying coupling, shown in Fig. 3, is designed to produce an output displacement which is either the product or the ratio of two inputs.

Several examples will show how these relatively simple elements can be combined to effect some rather unusual metering solutions.

Fig. 4 shows a metering system for measurement of heat transfer. The problem calls for a production of the record and integration of the amount of refrigeration for cost billing purposes. Water used in the building cooling system is cooled in an outside plant and returned to the building. Both the degree of cooling and the amount of water cooled are variable depending on weather conditions. The desired measurement is accomplished by multiplying the heat extracted per pound of water by the total pounds of water used and recording and integrating the resulting product. The heat extracted per pound

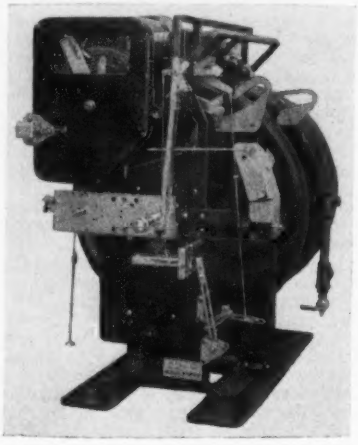

Fig. 1. Net Volume Meter. First ring measures flow; second ring measures specific gravity of alcohol in flowing solution, also compensates flow ring and records and integrates net volume of alcohol flowing in line.

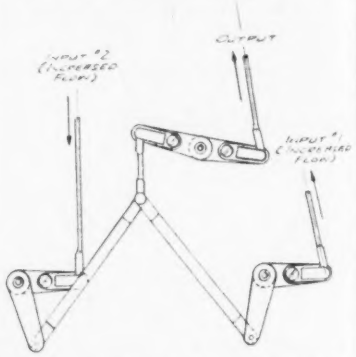

Fig. 2. Fundamental Summation Coupling

*Presented at the Fourth Annual Conference of the Instrument Society of America, Sept. 12-16, 1949, St. Louis, Mo.

†Vice President in charge of Sales, Hagan Corp., Pittsburgh, Pa.

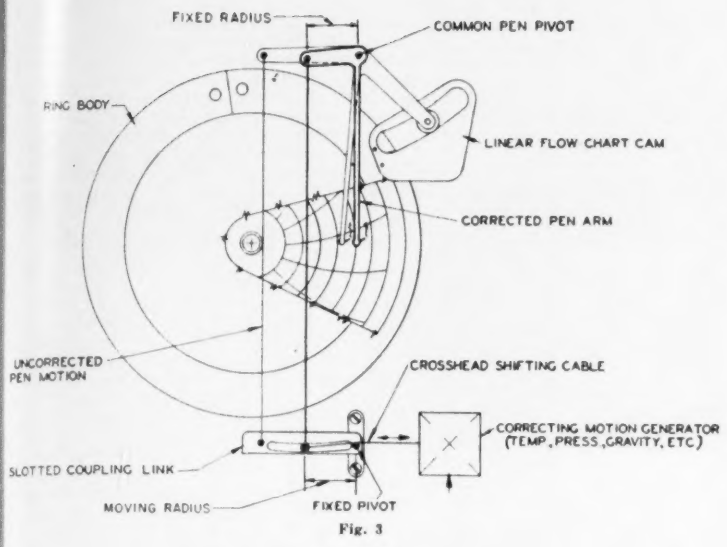

Fig. 3

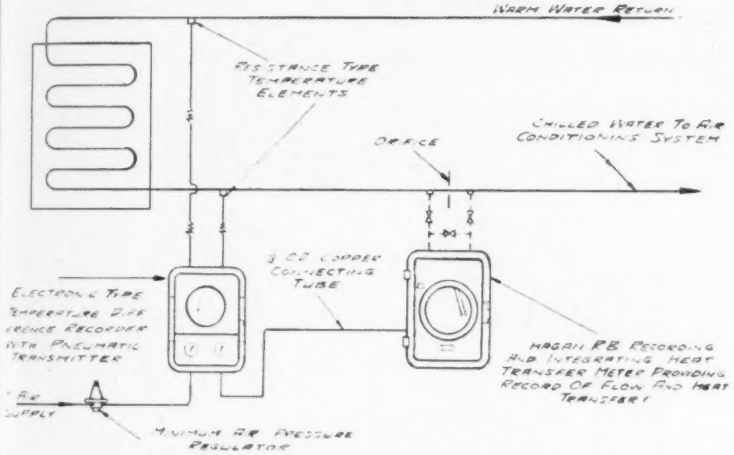
WARM WATER RETURN
RESISTANCE TYPE TEMPERATURE ELEMENTS
ORIFICE
CHILLED WATER TO AIR CONDITIONING SYSTEM
3/8" COPPER CONNECTING TUBE
ELECTRONIC TYPE TEMPERATURE DIFFERENCE RECORDER WITH PNEUMATIC TRANSMITTER
HAGAN R.B. RECORDING AND INTEGRATING HEAT TRANSFER METER PROVIDING RECORD OF FLOW AND HEAT TRANSFER
AIR SUPPLY
MINIMUM AIR PRESSURE REGULATOR

Fig. 4. Heat Transfer Metering System automatically multiplies rate of flow by temperature difference to provide record and integrating of heat transfer.

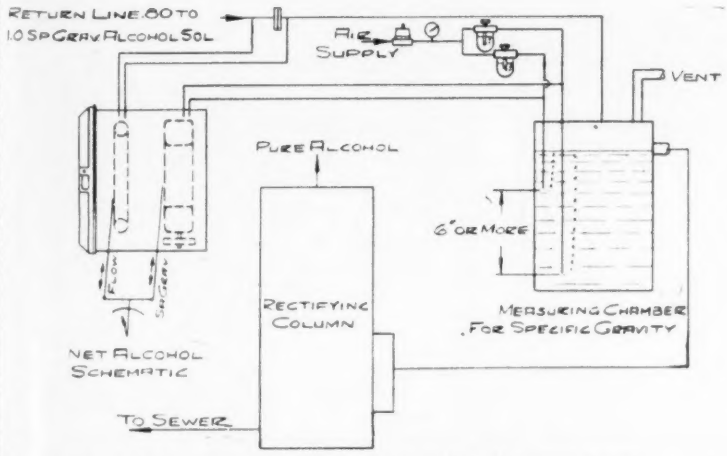

Fig. 5. Schematic Arrangement of Metering on Alcohol Recovery System.

of water is given by a measurement of the temperature difference between the outgoing and incoming water, while the weight of water is given by a conventional orifice type meter. In the system shown, a resistance type temperature difference recorder equipped with an air transmitter generates a pneumatic control pressure proportional to temperature difference. This pressure is applied to a bellows within the water meter housing and combined with the rate of flow by means of a multiplying coupling.

The output of the coupling operates a recording pen and integrator in the meter housing. Records of temperature difference, rate of water flow, and rate of refrigeration are provided with a continuous integration of the refrigeration. Cost billings are on the basis of the integrated readings.

Fig. 5 illustrates a net volume metering system. The problem calls for a record and integration of the amount of alcohol fed to a rectifying column. Both the volume of the water and the alcohol content per pound are variable.

The desired answer is obtained by determining the total solution flow and multiplying the total flow by the alcohol content to determine the net volume of alcohol.

The total solution flow is determined in a conventional manner by one element of a dual meter. The alcohol content is determined by a measurement of the specific gravity of the solution by means of the second element of the dual meter. The two readings are combined by means of the multiplying coupling to produce the desired record of alcohol flowing to the column.

Fig. 6 illustrates a gas flow measurement system. The problem calls for a record and integration of the gas flow in an interconnecting pipe line carrying gas under variable pressure, variable temperature, and variable specific gravity conditions. The desired record is one showing gas flow reduced to standard pressure, temperature, and specific gravity. Examination of the descriptive equation shows that the desired results can be produced by multiplying the square root of the gas density under flowing conditions by the square root of the orifice differential. Again, a dual meter is employed, one element of which is used to measure the square root of the gas main line orifice differential. The second element of the dual meter measures the square root of the orifice differential in an auxiliary flow system in which is located a constant volume pump. This auxiliary system is based on the fact that, at constant volume, orifice differential is proportional to fluid density.

A mutiplying coupling, of the type shown in Fig. 3, is employed to produce the product of the outputs of the two elements of the dual meter. The chart record carries three continuous records, one showing flowing density, the second main line orifice differential, and the third the rate of flow compensated for pressure, temperature, and specific gravity.

While the examples shown involve generally two main variables, the idea is not limited to such problems. It is possible, for example, to effect such computation in one meter housing, convert the result into a pneumatic con-

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trol signal, and introduce it to a second meter housing for combination with other variables. A further possibility lies in the combination of regulating elements with metering systems such as outlined above to produce other desired solutions.

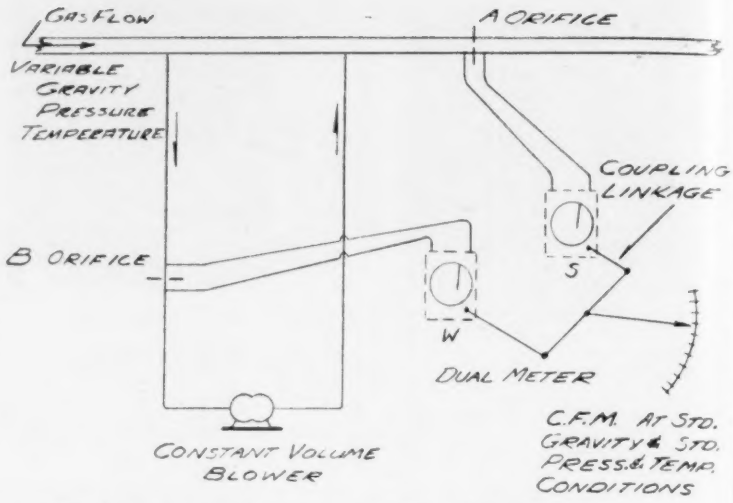


Fig. 6. Schematic Arrangement of Gravity-compensated Flow Meter. Measurement desired is cfm. equivalent in terms of base gravity, temperature and pressure. Meter "S" (spring-loaded) measures flow through orifice A. Meter "W" (wieght-loaded) measures density of gas at flowing conditions by measuring the differential across orifice B when constant volume flow rate is maintained. Coupling linkage combines readings of S and W to provide desired answer. Both meter (ring) S and meter (ring) W are in the same case.

Concepts Of Modern Gaging As Applying To Pneumatic Gages*

By LOUIS MAHLMEISTER†

OF ALL THE basic gaging devices, none has matched the pneumatic type for sudden rise in popularity, nor have any other type gaging devices been subjected to the same amount of intensive research.

The use of air in a controlled circuit for gaging purposes has been known for several decades, although it has only been within the last eight to ten years that it has taken its proper place in the gaging field.

Operational Advantages

There are many sound reasons for this change in popularity. It has permitted the gaging of elements which heretofore have been impractical or at best extremely tedious. Take for example the ordinary hole. While it is true we do have other gages of a fashion for this type of work, the use of air gages permits a complete analyzation of the hole for size, out-of-round, taper and bellmouth, and to any depth. It is one of the few gages which will determine back taper in a blind hole.

When we consider that internal dimensions comprise approximately 42 percent of all elements requiring accurate gaging, such advantages take on added significance.

Air gages may be used for checking narrow slots, splines, soft plated parts, thickness, flatness (with limitations), lengths, depths, etc. It is probably the only type gage suitable for measuring average diameter of parts in an out-of-round condition. A typical example of this latter condition exists in cylinder liners.

Complex Applications

Some of the more complex tooling permits the gaging of the squareness of the axis of a hole in relation to a face; the checking of the parallelism of the axes of two holes in relation to each other; the gaging of the "throw" in eccentric shafts; the checking of spacing between holes; measurement of center-distance in interrupted or figure "8" holes.

All of these dimensions are checked without the error normally caused by the diametral tolerance applying to the holes or shafts. In keeping with the current trend, fixtures are now designed to measure many of the part elements simultaneously.

An extremely easy entering air spindle for checking large diameters.

External Dimensions

It should not be assumed that air gages are suitable only for internal work. The availability of other types of precise comparators for external work necessitates a complete analyzation of the gaging problem before a choice is made. Many successful applications in the field have proven the merit of air gages for measuring large parts, thin-walled parts, wall thicknesses, the classification of diameters and multiple combinations of internal and external elements.

Principle of Operation

Essentially air gaging depends on the flow of air between the faces of jets or specially constructed heads and the part being gaged. In exceptional cases, however, plungers, balls or levers may make a physical contact with the part forming a variable aperture through which the air flows, giving a value.

Type of Base Instruments

All air gages can be classified into one of three basic principles: (1) Back pressure type; (2) Water type; (3) Flow type.

In its original fundamental form, the air gage consisted of an air supply of constant pressure entering an orifice of pre-determined size connected to the gaging head with suitable conduit. In this conduit was placed a pressure-indicating gage. The fit of the part on the gaging head formed an opening varying in size according to the size of the part being measured. A closely fitting part restricted the air flow more than a loosely fitting part, setting up a relative back pressure. This back pressure actuated the pressure indicator, giving a reading.

Air gages which depend upon a varying pressure at the gaging head are known as "Back pressure" type air gages. These may be further subdivided into a mechanical type and a water-column type.

The mechanical back-pressure air gage normally consists of first, a filter to remove excess moisture and other foreign materials which might soil the part being gaged or foul the small orifice through which all the air must pass; second, a mechanical pressure regulator valve through which air passes to give a constant pressure.

*Presented at the Fourth Annual Conference of the Instrument Society of America, Sept. 12-16, 1949, St. Louis, Mo.

†Sheffield Corp., Dayton, Ohio.

Ordinarily with a constant pressure presenting air to given-size orifice, one would expect a constant rate of flow. It will be well to note that in this case this is not true, as the varying pressure between the orifice and the gaging head exerts a back pressure that decreases or increases this flow. This back pressure is controlled by the ratio between the orifice and the escape permitted by the engagement of the gaging head with a maximum or minimum part.

Pressure Considerations

It is obvious that a pressure must be established in the conduit that will allow exactly the same amount of air to flow from the jets as will enter the conduit, under a constant head at the orifice against this established pressure. The process of balancing these flows against one another is automatic, and the lag is the product of the proportion between the volume of the conduit and the rate of flow at the gaging head.

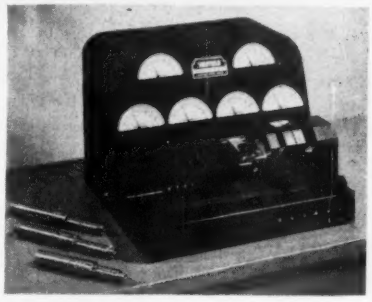
If the conduit is extremely small and the rate of flow at the gaging head great—as in the application of a low-amplification gage setup with the gaging head very close to the instrument—balance takes place quickly and speed of indication is remarkably good. If, however, the gaging head is used at a greater distance from the instrument, increasing the volume of the conduit, this indicator reaction will slow.

Likewise, if the rate of flow is decreased as by reducing the clearance between the gaging head and the part—as required to get a greater gage amplification—the speed of indication is decreased. Therefore, very definite limitations in both amplification and remote gaging are imposed to retain an acceptable sensitivity or speed of indication.

Water Type

The water-column back-pressure air gage is identical to the mechanical back-pressure gage in operation and theory but differs in the method of accomplishment. It consists of a vertical tank of water into which a tube has been inserted with an open end near the bottom of the tank. Into the upper end is introduced the air supply, sufficient in quantity to remove all water inside the tube.

Surplus air bubbles out, keeping this level at the bottom of the tube constant. This establishes a constant pressure in the tube that may be changed only by changing the water level in the tank. At the upper closed end of this tube is an orifice allowing air to enter a conduit leading to the gaging head, as in



Gaging six diameters on a refrigerator crankshaft with dial-type air gages.

the previously described gage. A small vertical glass tube has one end connected to this conduit and the other end to the lower portion of the water tank. Obviously this tube will indicate the height of the water level in the tank when atmospheric pressure prevails in the conduit. Increasing back pressure in the conduit depresses the water level in the glass tube, making a direct-acting pressure indicator.

This system has the same functional limitations as the mechanical back-pressure gage, plus practical limitations on gaging pressure. Because of the height of water tank necessary, this gage seldom operates at over 1-lb. pressure. The simple design eliminates most mechanical units.

Flow Type

A more recent development is the constant-pressure rate-of-flow air gage, which permits nearly unlimited amplification and features extreme simplicity in construction. The unit consists of a filter to remove foreign material and moisture from the air supply. Next a primary pressure regulator valve is adjusted so as to maintain a pressure of several pounds higher than a secondary valve and avoid wide fluctuations from approaching the final regulator. The air then passes into a secondary pressure regulator for further reduction.

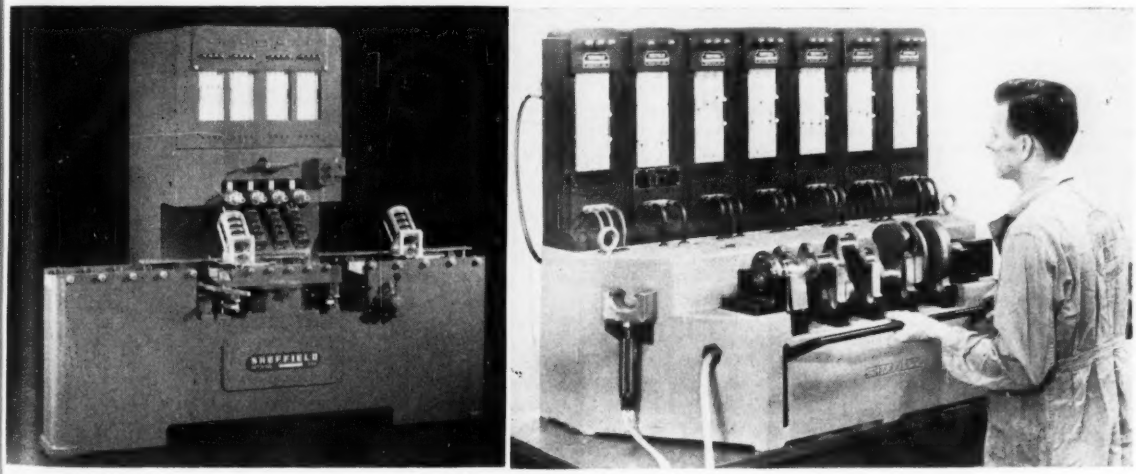
The flow type air gage differs from the back pressure type in the elimination of the restricting orifice and the pressure indicator. In their place, a rate-of-flow meter is provided between the valve and the gaging head. The rate-of-flow meter employed, consists of an internally tapered transparent tube—positioned vertically with the large end upward. A light-weight specially designed metal float positions itself in the taper according to the velocity of air passing through the tube. The float position is a direct rate of flow indication. It will be noted that no restriction occurs between the regulator valve and the gaging head, therefore, the pressure presented to the part at the gaging head is constant.

This principle permits instantaneous action regardless of the distance separating the indicating tube and the gaging head. Installations have been made wherein the gaging head has been located 50 feet from the instrument with no apparent time lag in indication.

Additional controls have been provided for the adjustment of amplification, within its limits. Another control permits the zeroing of the float to an accurately graduated linear scale. Such features combine to make this an outstanding gage for use in machining operations, in the preparation of Quality Control charts, for use in inspection departments, for assembly purposes and many other places which require a fast and accurate means for dimensional determination.

Achieved Economies

The economies obtained in using air gages are manifold. Wear life is extremely long and original accuracy maintained throughout the usable life of the tooling. Identical readings are obtained regardless of operator experience which permits the use of lower skilled personnel. The speed-accuracy ratio is considerably higher than obtained with other gages. Accuracy in readings assures the use of *all* acceptable parts and the rejection of *all* parts beyond tolerance limits. Unquestioned accuracy avoids time consuming arguments, mistakes and assembly diffi-



Semi-automatic machine (left) for checking and classifying cylinder bores in an automotive block. Measuring 20 diameters (right) on an automotive crankshaft.

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culties. One operator may do the work of many by means of multiple applications.

The examples given are just a few of the many advantages obtainable from air gage applications. The field is still so new that actually and figuratively speaking, the surface has not been scratched, application- or production-wise. From all indications the next few years will show an even more amazing progress in this field.

Section Secretaries, Meeting Data and Programs

AKRON
Fred Appel, 932 Columbia Ct., Barberton, Ohio. Tel: SH 3440
Fourth Tuesday, Meeting at 7:30 P. M., Akron Y.W.C.A.

ALBUQUERQUE
L. J. Paddison, 911 Parkland Circle, Albuquerque, N. M. Tel: 5-1806
First Monday, Meeting at 8:00 P.M., Science Lecture Hall, Univ. of N. M.

ARUBA
K. H. Walker, P. O. Box 389, c/o Lago Oil & Transport Co., Ltd., Aruba, N.W.I.
First Tuesday, Meeting at 7:15 P. M.

ATLANTA
H. Kockritz, Fischer & Porter Co., 84 Peachtree St., Atlanta, Ga. Tel: CY 1269
Fourth Monday, Meeting at 7:45 P.M., Ga. Institute of Technology.

BALTIMORE
George B. Greer, 631 E. 36th St., Baltimore 18, Md. Tel: Chesapeake 6879
Second Friday, Meeting at 8:00 P.M., Engr's. Club of Baltimore.

BATON ROUGE
John Q. Bass, 1517 Longwood Dr., Baton Rouge. La. Tel: 3-0283
Meeting at 7:30 P.M., L.S.U. Physics Bldg.

BOSTON
C. J. Nazzaro, 456 Central Avenue, Milton 87, Mass. Tel: CU 6-2479
Last Wednesday, Dinner at 6:30 P. M., Meeting at 7:00 P.M., Patten's Restaurant.

CALIFORNIA
D. C. Duncan, Helipot Corp., 916 Meridian Ave., S. Pasadena, Calif. Tel: SY 4-8439
Second Wednesday, Dinner at 6:30 P. M. Meeting at 8:00 P. M.

CENTRAL ILLINOIS
H. F. Lange, 2101 W. Glen Avenue, Peoria 5, Ill. Tel: Peoria 5-4516
First Wednesday, Dinner at 6:30 P.M., Meeting at 7:30 P.M.

CENTRAL INDIANA
H. F. Coffey, 4029 N. Temple Ave., Indianapolis, Ind. Tel: HU 5832
First Tuesday, Meeting at 7:30 P. M.

CENTRAL NEW YORK
Karl W. Robertson, Minneapolis-Honeywell Reg. Co., 121 W. Onondaga St., Syracuse, New York.

CHARLESTON
Clayton A. Williams, 303 E. 9th St., Belle, W. Va. Tel: 927871
First Monday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Kanawha Hotel.

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Floyd E. Ertaman, Rm. 1420 Fisher Bldg., 343 S. Dearborn St., Chicago, Ill. Tel: WE 9-0686
Third Tuesday, Dinner at 6:45 P. M., Meeting at 8:00 P.M., W.S.E. Auditorium.

CHINA LAKE
A. H. Staud, 1004 Michelson Lab., USNOTS, China Lake, Calif. Tel: 77882
Fourth Thursday, Meeting at 8:00 P.M., Michelson Lab, USNOTS.

CINCINNATI
Edward H. Muhleisen, 320 Durrell Ave., Cincinnati 15, Ohio. Tel: PO 1168
First Monday, Meeting at 8:00 P.M., Eng'r. Society Hqs.

CLEVELAND
A. E. Ehrke, 1732 East 291st St., Wickliffe, Ohio.
Fourth Wednesday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Cleveland Eng'r. Society.

COLUMBUS
Orval Linebrink. c/o Battelle Memorial Institute, 505 King Ave., Columbus, Ohio. Tel: UN 3191, Ex. 248
Third Thursday, Battelle Auditorium

CUMBERLAND
Clyde Babst, 225 Cecilia St., Cumberland, Md. Tel: 583-W
Tuesday after Fourth Monday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Algonquin Hotel.

DETROIT
Seymour Sterling, 18331 Linwood, Detroit, Mich. Tel: Tyler 5-1707
Second Wednesday, Meeting at 8:00 P.M., Rackham Bldg.

EASTERN NEW YORK
W. R. McKegg, c/o Gen. Engrg. & Consulting Lab., G. E. Co., Schenectady, N. Y.
First Tuesday, Dinner at 6:30 P.M., Meeting at 8:00 P.M.

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Third Tuesday. Meeting at 7:30 P.M., Lamar College.

HOUSTON
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Last Monday, Meeting at 8:00 P.M., Engineers Club.

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L. E. Oberhelman, Standard Oil Co., Sugar Creek, Mo. Tel: MU 1227
First Tuesday, Meeting at 7:30 P.M., Univ. of Kansas City.

LOUISVILLE
H. C. Scherffius, 980 Palatka Rd., Louisville 8, Ky. Tel: Franklin 1265
Fourth Tuesday, Meeting at 8:00 P.M., Seagram Auditorium.

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S. J. Mizuhara, 1075 Allard, Verdun, Quebec, Canada. Tel: TR 3252
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First Tuesday, Dinner at 6:00 P. M. Meeting at 8:00 P.M., Essex House.

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W. H. Haney, 2927 Music Avenue, New Orleans, La.
No Regular Date, Meeting at 8:00 P.M.

NEW YORK
Norman J. Cherry, P. O. Box 608, Merrick, L. I., N. Y. Tel: Freeport 9-4127
Last Monday, Meeting at 7:30 P.M., Statler Hotel.

NIAGARA FRONTIER
Mrs. James L. Martin, 697 Potomac Ave., Buffalo 9, N. Y. Tel: GR 1450
Fourth Monday, Dinner at 6:15 P.M., Meeting at 8:00 P.M., Institute of Arts and Sciences, Buffalo.

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NORTHERN INDIANA
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Third Wednesday, Dinner at 6:30 P.M., Meeting at 7:30 P.M., Gary Y.M.C.A.

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John H. Clark, 230 Canton Hall, Oak Ridge, Tenn. Tel: 5-9142
First Wednesday, Dinner at 6:30 P.M., Meeting at 7:30 P.M., Oak Terrace.

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John W. Huether, 311 Southerland Dr., Leaside, Ontario, Canada. Tel: HU-7114
Third Thursday, Dinner at 6:45 P. M. Meeting at 8:15 P. M. Friendship Hall, College St. United Church, Toronto

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R. E. Harris, 228 Mays Bldg., Amarillo, Texas. Tel.: 31434.

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C. W. Wood, 6908 Market St., Upper Darby, Pa. Tel: Clearbrook 9-3959
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Miss Louise Suckfield, P.O. Box 2038, Pittsburgh 30, Pa. Tel: Hi 1-6880
Fourth Monday, Dinner at 6:30 P.M., Meeting at 8:00 P.M., Rooseveit Hotel.
Pittsburgh Inspection & Gaging Committee. Second Tuesday, Meeting at 8:00 P.M., Wm. Penn Hotel. Tel: CE 1-5621

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Fourth Tuesday, Meeting at 8:00 P.M., G. E. Community Center, East Lake Rd.

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M. T. Slind, M-6, Rm. 107, Richland, Washington Tel: 4615-R
Second Wednesday, Meeting at 7:30 P.M., American Legion Hall.

ROCHESTER
R. C. Schwarz, Jr., 1201 Granite Bldg., Rochester 4, N. Y. Tel: Monroe 4610R
Fourth Tuesday, Meeting at 8:00 P.M., Univ. of Rochester, Physics Lecture Hall.

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Fred T. Yorke, P. O. Box 213, Point Edward, Ontario, Canada. Tel. 2363J
Second Friday, Meeting at 8:00 P.M., Moose Hall.

SOUTH BEND
Sam M. Rouse, 436 Moccasin Ave., Buchanan, Mich. Tel: 678
First Thursday. Meeting at 8:00 P.M., Engineers Club, Hotel La Salle, South Bend.

SOUTH MICHIGAN
Larry DeHaan, 1117 Cobb Ave., Kalamazoo, Mich. Tel: 2-0385
Fourth Wednesday, Dinner at 6:30 P.M. Meeting at 8:00 P.M., Chicken Charlie's, Kalamazoo.

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H. C. Givens, La Gloria Corp., P.O. 637, Falfurrias, Texas. Tel: 122-W
First Thursday. Meeting at 7:30 P.M., Garner Aircraft Instrument School.

ST. LOUIS
W. G. Lee, 4710 Delor St., St. Louis 16, Mo. Tel: FL 8516
First Wednesday, Meeting at 8:00 P.M., Engineers' Club of St. Louis.

TOLEDO
Morrison L. Conner, Toledo Edison, 925½ Sherman St., Toledo, Ohio.

TENNESSEE
N. M. Taylor, 16 Edgewood, Kingsport, Tenn. Tel: 3338J
No definite night, Dinner at 6:45 P. M., Meeting at 8:00 P.M.

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C. R. Horton, 8211 E. 7th, Tulsa, Oklahoma Tel: 92-1434
First Monday, Meeting at 6:45 P.M., Engineering Bldg., Tulsa Univ.

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WAYNE COUNTY
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Third Monday, Dinner at 6:30 P.M., Meeting at 8:30 P.M., Poremba Hotel, Ecorse, Mich.

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High-pressure Design *and* Application *of* Control Valves *and* Regulators

By J. H. COPE, Fisher Governor Co., Marshalltown, Iowa.

Introduction

The design and application of regulators and control valves for present-day high-pressure operations in steam power plants, in the process industries and in petroleum and gas field operations, have introduced new problems and considerations for both the design and application engineer. The handling of high-pressure applications has been extended by discovery of newer materials, alloys, etc., and by new design principles. Coupled with ingenuity and the knowledge gained of experience, the designer has made notable advances in meeting particular design problems of high-pressure applications.

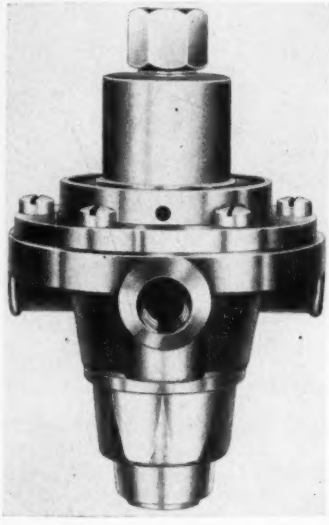

Fig. 1. High-pressure Self-contained Regulator.

The purpose of this article is to outline some of the aspects of high-pressure design, to discuss some of the more important problems encountered and to summarize certain developments in high-pressure design and application that will be informative and helpful to the user and application engineer.

Direct-operated Regulators

In any discussion of valves for high-pressure control, the direct-operated regulator should not be neglected. While its application is limited, it still finds use in high-pressure regulation of small and moderate volumes, or as constant-pressure hydraulic and pump governors, under relatively steady load conditions.

Examples are found in gas cylinder regulators and high-pressure gland seal regulators on pumps, operating-supply regulators and high-pressure service regulators. Fig. 1 is a typical high-pressure self-contained operating-supply regulator, used for reducing the pressure of the supply to a pilot in gas field pressure controllers, where the high-pressure gas is used as the operating medium. Designed for 3000-psi. working pressure with heavy forged-bronze body and stainless-steel diaphragm, such a regulator is usually made in small sizes, quarter-inch, with capacities from 1 to 5 cfm. Fig. 2 is typical of a high-pressure field service regulator, with high tensile iron body designed for 1000-psi. inlet pressure and with wide range of reduced pressures from 200-psi to 5 psi., in 1-inch and 2-inch sizes with capacities ranging from 100 cfm. and lower, depending upon operating conditions. It is interesting to note the use of Du Pont Teflon, one of the new plastics, as a seat disk of excellent performance, in this valve, under high-pressure drop conditions.

These self-contained regulators do not pose any particular problems in design, if one works within the limits of materials available. Strength of body, diaphragm casings and bolting must be suitable for the maximum working pressures. Diaphragm and spring combinations are dictated by the regulated pressure range to be covered, at the same time holding within the strength limits of available materials. The orifice or port area must be limited not only to obtain good throttling characteristics, but also to keep the unbalanced force across the seat, due to high differential pressure, within the limits of loading obtainable with the appropriate spring-diaphragm combination.

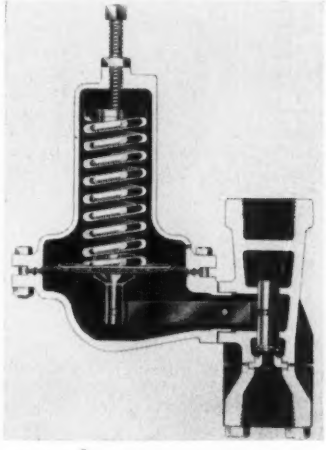

Fig. 2. High-pressure Field Regulator.

Direct-operated constant-pressure hydraulic or pump governors are generally limited to about 300 psi. with the conventional diaphragm and spring operator. For higher pressures, a piston and spring operator is common. Again, the spring and piston area combination is determined by the operating range, at the same time observing the limits of material strength. Fig. 3 illustrates a typical regulator in this class, which is designed for an operating range of 1500 to 7000 psi.

Control Valves

Broadly classified, control valves should include manual- and power-operated valves, electric-motor, hydraulic-cylinder or diaphragm-motor

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operated. The problems of high-pressure design are common to all these classes in greater or lesser degree. The most widely used with automatic control or pilot regulation is, of course, the diaphragm-motor valve, and the discussion will be limited to this type, remembering that similar problems of design and application apply as well to other types.

Fig. 4 illustrates the cross section of a typical diaphragm-motor valve with double-seated body and trim. For high-pressure application, particular attention must be given to mechanical design of the:

Body
Bonnet
Stuffing Box
Diaphragm Motor Assembly
Internal Details

Fig. 3. Constant-pressure Hydraulic or Pump Governor.

Design and operating conditions and process application requirements direct the attention of both the designer and process engineer to the factors of:

Type Body and Inner Valve
Inner Valve Trim
Design and Characteristics of the Diaphragm Motor

This classification into factors of mechanical design and process requirements is not necessarily exact or limiting, for they are dependent upon one another in many cases and the process engineer often must consider the mechanical design in addition to process requirements.

Mechanical Design

The first consideration is that the valve body assembly be designed for the specified static pressure and temperature conditions. The material of construction is dictated in part by the nature of the fluid to be handled and by temperature. Metal thickness, flange dimensions for connections, bonnets and blinds and bolt and stud dimensions are normally based on accepted standards and specifications such as ASA, ASTM, etc. These are well known and need no further comment.

Common types of bonnet construction are threaded and bolted. Fig. 5 illustrates a typical threaded body valve with threaded bonnet which is suitable for pressures up to 6000 psi. The limitation of this type construction is temperature, and above 450 F. this type bonnet is subject to leakage due to temperature gradient and differential expansion effects. Fig. 6 illustrates a typical flanged body valve with flanged bonnet, designed for 1500-psi. nominal rating. A third type of bonnet construction widely used for high pressure and high temperature applications is the so-called "pressure seal" bonnet, Fig. 7. This type utilizes the static pressure within the valve body to apply the loading to a piston-like bonnet and sealing ring; and it is an adaptation of the type of closure long used in high-pressure techniques. Its particular advantage lies in eliminating the massive flanges required with bolted bonnets as shown in Fig. 6. Note that the sealing ring gland has Acme type threads to stand high loading from internal pressure.

In high-pressure stuffing box design, the principal requirement is to have sufficient depth of packing to prevent excessive leakage without introducing undue frictional drag on the valve stem. Good practice has been to maintain a ratio of packing depth to stem diameter of 5 or 6 to 1. In addition, a lantern gland is normally included and a selected lubricant is introduced under pressure from a suitable pressure fitting and isolating valve, to act as a combined seal and lubricating film. Such construction has proved effective up to pressures of thousands of pounds, using suitable packing material and lubricant. Bolted glands are usual for pressures above 400 psi. See Fig. 6.

Recently, interest has centered in Teflon as a packing material, and special designs employing this compound have proven their worth in high-pressure applications and, as well, in services where lubricants are undesirable. One design for high-pressure work uses a specially-shaped single-piece packing member of Teflon, which has a tapered portion facing into the direction of high pressure. The stuffing box and gland are so constructed that the pressure acts on the outside of the tapered portion and squeezes the thin leading edge around the stem to form the effective pressure seal. Other designs have retained the general character of the conventional stuffing box with multiple-ring packing, except that molded rings of Teflon are used, and modifications are introduced to handle the particular properties of this plastic. Rings are molded in the inverted V or chevron shape to utilize the pressure sealing effect of the feather edges of the V around the stem. It has been found that the effective packing depth may be materially decreased, and a lubricant is not required to act as a seal. Actually, Teflon is not self-lubricating, as might possibly be believed, but its surface character is such that no lubrication is required to keep down stem friction.

The diaphragm-motor assembly must obviously be designed with sufficient mechanical strength for the maximum loads to be encountered which are those in the diaphragm head, from air loading pressure, from stem loads, from static and unbalanced forces on the inner valve stem. Depending upon the size and particular type of valve as well as the working pressures involved, stem thrusts may amount to as much as 3000 to 5000 pounds in extreme cases. This requires that stems and stem connectors be designed accordingly. The manner of securing the yoke to the valve bonnet must be adequate to withstand such loads without separating or cocking. The latter is important to maintain alignment. Correspondingly, the diaphragm and spring must be of suitable proportions and design for the stem loads encountered. The valve of Fig. 5, which is limited to 2 inches in size with 1-inch inner valve, has a slip on type yoke construction locked in place with hardened set screws. Such construction is suitable for stem loads encountered in this valve, and the diaphragm and yoke structure are correspondingly relatively light. However, on larger valves with more severe

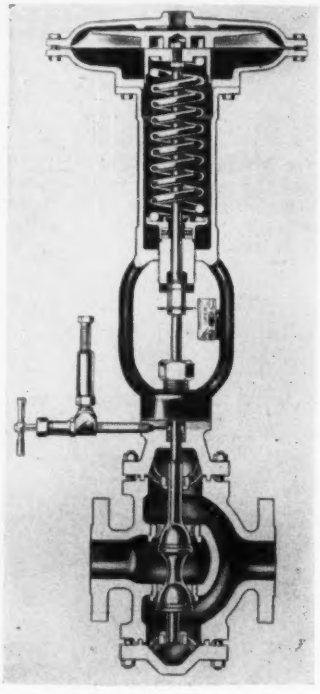

Fig. 4. Double-ported Diaphragm-motor Control Valve.

conditions imposed, bolted yokes are used, massive diaphragms and structures are required, as shown in the valves of Fig. 6 and Fig. 8. More will be said later about the diaphragm-motor assembly in consideration of operating conditions and process application requirements.

In considering the internal details of the valve body, the choice of trim material and type of inner valve are more properly dictated by operating conditions than by pressure requirements. However, in high-pressure application, the associated problems of high velocities are generally encountered and this leads to consideration of guiding of the inner valve. Double-ported valves are now commonly furnished in top- and bottom-guided construction for high pressure drops, as are also large size single-seated plugs (Fig. 4). Small size single-seated valves (Fig. 5) and certain special purpose valves (Fig. 8) have extra-large heavy-duty guide members to insure correct alignment of the plug with the seat or orifice. This heavy-duty guiding is important to eliminate vibration or chatter as a consequence of high velocity flow through the body.

Operating and Process Requirements

The problems encountered in meeting the operating and process requirements in high-pressure control valve applications are the more interesting. Mechanical design can generally be satisfied by following proved rules and formulas and the application of good design practice. In order to meet certain operating conditions and requirements, considerable ingenuity has been exercised by the designer and frequently the solution has been the consequence of trial and experience in practical applications. In this respect, the process and application engineers have come to understand and appreciate the limitations of design in particularly rigorous applications.

Type of Body and Inner Valve.—The nature of the fluid handled and the operating requirements generally determine the type of body and inner valve to be used. If tight closure is required, the single-seated plug is indicated, while if the requirements are merely for throttling control, the double-ported valve gives greater capacity for a given body size, and unbalanced forces across the valve plug tend to be balanced out.

Regarding the valve characteristic, this is usually based on operating and process conditions and generally the process engineer has an available choice of "parabolic," "equal-percentage" or "linear quick-opening." No attempt will be made to delve into the choice of valve characteristic as this is not specific to the problem of high-pressure applications and, besides, much has been already written on the subject by others.

In general, either the skirt or formed type plug is equally adaptable to high-pressure services. On very high pressure-drop applications and on fluids carrying suspended solids or displaying severe erosive conditions, general practice is to go to the formed type plugs as the smooth contour is considered less subject to wear under such circumstances.

Typical of a valve developed especially for high-pressure service on oils with coking properties and for handling high pressure drops and flashing conditions in power plant applications is the body assembly shown in Fig. 8. This angle type body has the high pressure brought in over the seat and the flow is into the outlet through the venturi shaped nozzle. This reduces turbulence within the body and consequent wear on the internal trim. On high pressure drop applications where flashing occurs, this design permits the major portion of the flashing to take place after the valve, in the usually enlarged outlet piping. Thus no excessive back pressure is built up within the valve body and substantially full capacity is available.

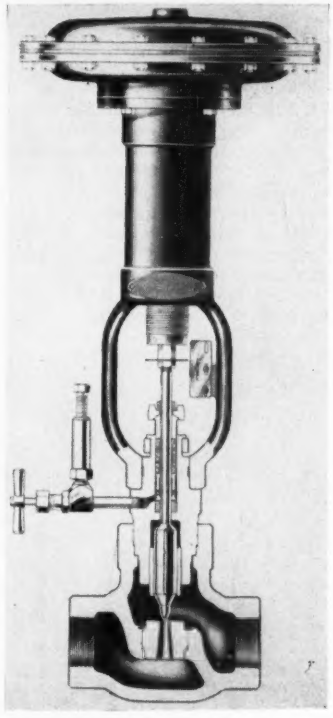

Fig. 5. 6000-psi. Cold Working Pressure Diaphragm-motor Control Valve.

High pressure-drop applications have emphasized the importance of dynamic as well as static unbalanced forces on the inner valve and valve stem. Dynamic unbalance forces are experienced in valves of double-ported design, in their most serious effects, and their magnitude increases directly as the pressure drop or velocity through the valve.

In the formed or parabolic type of inner valve of conventional design with top and bottom portions identical, it has been found that the net force on the stem due to dynamic or flow reaction effects shows a reversal as the valve travels through its lift, and that the magnitude of this reversal is greater at higher pressure drops. For example, refer to the valve shown in Fig. 4. In the closed position, the slightly larger area of the bottom port causes a net unbalanced force downward (tension) on the valve stem by reason of the pressure differential across the plug. As the valve is gradually opened, this net force decreases to zero and then reverses direction exerting a net force upward (compression) on the valve stem. The over-all effect is to change suddenly the net load on the diaphragm motor and, if this reversal is of sufficient magnitude, instability of the diaphragm-motor valve action results. Such effects have been noted in practice. Skirt type inner valves have exhibited the same reversal though to a considerably less (almost negligible) extent.

On the other hand, conventional skirt type plugs, having similar top and bottom sections, show very strong torque or spinning tendencies under high pressure-drop conditions and in the larger sizes where the diameter (spinning couple) is great. Such effects have been strong enough as to shear locking pins and drop the plug from the stem.

These dynamic effects are hardly subject to any degree of quantitative analysis because of the complications in the fluid mechanics involved. Rather, the solution has been the result of experience and research in the laboratory which has resulted in new concepts of inner valve or plug design to eliminate or minimize these undesirable reactions to the degree that they are negligible.

Stem loads due to static unbalance forces must be considered in determining stem size and force requirements of the diaphragm-motor assembly. For example, consider again the valve pictured in Fig. 4. Let us take a typical case of a 4-inch valve controlling the flow from the bottom of a high-pressure absorber at 1000 psi. to a second column operating at 800 psi. The maximum unbalance load on the valve stem due to difference in seat areas in this valve is downward as a result of the slightly larger diameter of the lower plug. This differential area, 0.773 square inches, multiplied by the maximum pressure differential of 200 psi., gives a stem load of 154.6 pounds. Normally this valve would have a half-inch stem and the second unbalanced load would be an upward force on the stem of 0.196 square inches, multiplied by the downstream static pressure of 800 psi., equal to 156.8 pounds. It is apparent then that the unbalanced load due to high static downstream pressure cannot be neglected in this case and must influence the design of the diaphragm motor. Total stem load in this case is well within the limit for a half-inch stem.

Inner Valve Trim.—The type of internal trim or materials used in the

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inner valve parts including the plug, seat rings and guides is usually selected on the basis of the nature of the flowing fluid and, equally important, on the basis of the operating conditions of pressure and temperature. Beside corrosion resistant properties, hardness and non-galling characteristics are factors to be considered.

The most common trim materials are 302 and 316 stainless steel. The latter is preferable because of its greater corrosion resistance and slightly greater hardness (150-200 Brinell). Where high pressure drops and velocities are encountered, to magnify erosive effects and wire drawing, it is common practice to hard-surface the seats of the plug and ring with a material such as Stellite. This alloy is typical of the hard non-ferrous metals and the No. 6 material, the most widely used, has a hardness of 375-415 Brinell. This is readily laid on with an acetylene torch, as shown in Fig. 9, prior to final machining. If high temperature conditions accompany high pressure, the guides and guide bushings as well are hard faced to prevent galling of the sliding surfaces. Fig. 10 illustrates a complete hard-faced assembly in which Stellite is laid directly into the body to form integral seats.

Type 440 stainless steel (375-534 Brinell) is also used for inner valve trim on severe applications. The valve of Fig. 8, for example, is commonly furnished with hardened 440 stainless plug and liner. If high temperature is encountered, the plug and liner are hard-chrome-plated to present non-galling surfaces.

For the most severe conditions of high pressure drop in fluids containing abrasive solids, and where usually valves of relatively small size are used, Tungsten carbide tips and seat inserts have been applied. Carboloy, which is next to the diamond in hardness, is formed into molded plug tip and seat ring insert which are silver soldered in place as shown in Fig. 11. Carboloy is not suitable for corrosive conditions, however, and certain fluids tend to dissolve the binder.

Design and Characteristics of the Diaphragm Motor.—One of the more important considerations in high-pressure diaphragm-motor valve design and specification is the diaphragm motor itself. This mechanism, which supplies the power to position the inner valve or plug in response to a given output pressure from an instrument or pilot, must satisfy the necessary requirements of: (a) positioning the valve accurately over its full travel range for full output pressure range from the instrument or pilot and (b) at the same time be capable of supplying the additional force necessary to counter frictional and unbalanced loads imposed on the valve stem.

The familiar spring-opposed diaphragm motor in itself is limited to the extent in which it can fulfill these two basic requirements when it comes to the question of high-pressure applications with large unbalanced forces. Fundamentally, the relation of spring rate to diaphragm area is fixed by the valve travel and normal diaphragm loading pressure range, i.e., instrument output pressure range. Thus, for an instrument output pressure range of 3 to 15 psi. (12 psi. change) the spring rate, or force to compress the spring one inch, is determined by

$$\frac{\text{diaphragm area} \times 12 \text{ psi.}}{\text{inches travel}}$$

Large diaphragms and correspondingly stiffer springs provide a greater positioning force per unit change in loading pressure, which aids in overcoming frictional effects. However, in order to supply additional force to meet unbalanced stem loads, either (a) the spring preloading must be increased or (b) the instrument output pressure range must be increased beyond the normal spring range. On any

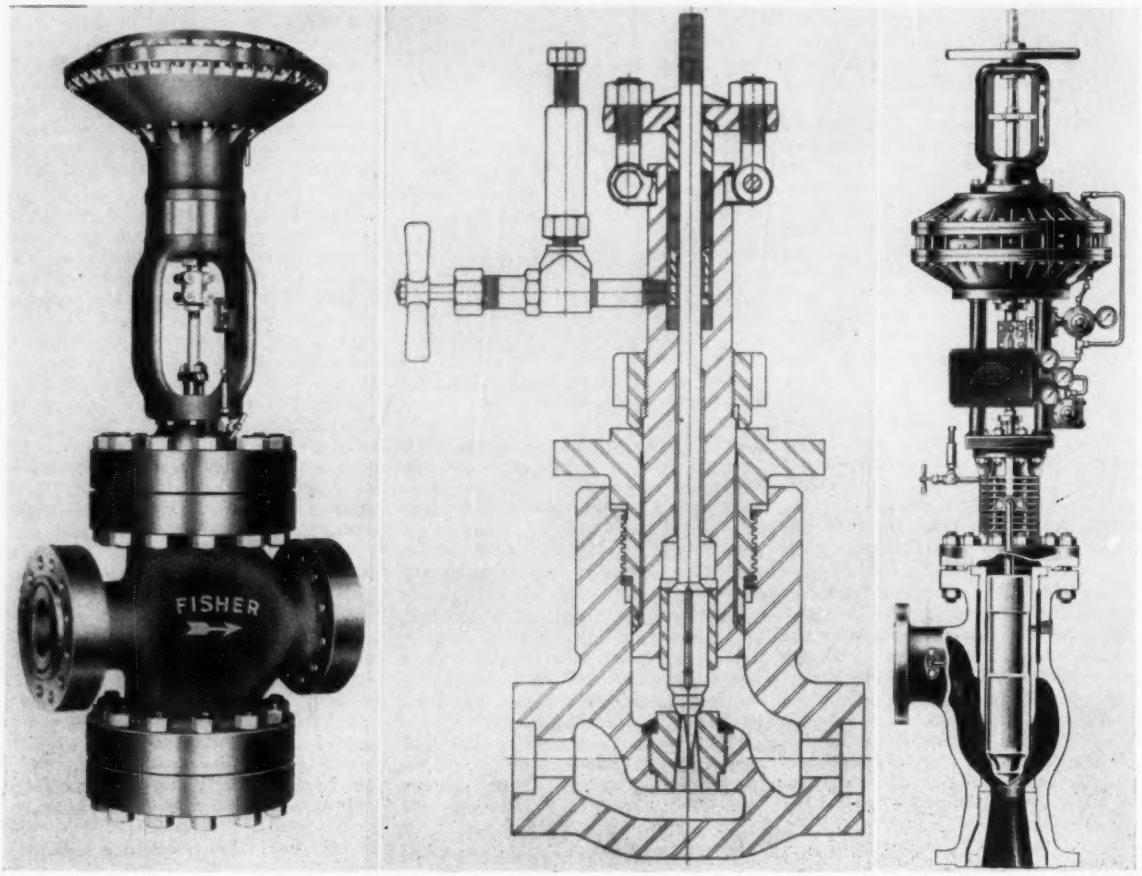

Fig 6. (left) 1500-psi. Diaphragm-motor Control Valve. Fig. 7. (center) Control Valve Body Assembly with Pressure Seal Bonnet. Fig. 8. (right) Angle Body Valve with Venturi Type Trim and Springless and Diaphragm Motor.

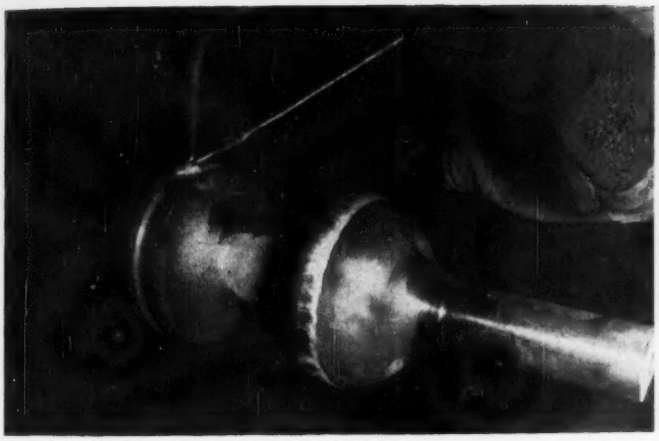

Fig. 9. Welding on Hard Surface to Valve Plug Seat.

given spring, preload cannot be increased without correspondingly sacrificing total travel. Instrument output air range may be changed, but only within narrow limits imposed by the instrument design.

For example, consider a diaphragm-motor valve, which is to be operated from an instrument whose normal output pressure range is 3 to 15 psi., and which has a spring and diaphragm combination arranged for full travel with a 12-psi. change on the diaphragm. If unbalanced stem force opposes the direction of the spring load so that it must be preloaded with a force equivalent to 5 psi. on the diaphragm, then the effective pressure change to stroke the valve is reduced to 10 psi. and the travel is correspondingly shortened. If, however, the instrument output range can be changed to 3 to 17 psi., then the 12-psi. range is again available for full valve travel.

A valve positioner, which is a relay positioning device that will apply any air pressure on the diaphragm, up to the limit of its supply, to position the valve stem, extends the range of unbalanced loads that the spring-diaphragm motor can handle without sacrificing travel range. For example, if a valve positioner with a 25-psi. supply, and a travel range pressure of 12 psi. (equivalent to 3-to-15-psi. instrument output range) is mounted on this valve, then the effective pressure range for positioning the valve will be 5-to 25 psi., or 20 psi. In fact, unbalanced loads equivalent to 10 psi. on the diaphragm could be handled and still leave a minimum of 3 psi. additional loading to overcome frictional forces.

The springless or air-loaded diaphragm motor is problably the most effective solution to problems of high-pressure unbalanced stem forces of large magnitude. In this type of operator, the spring is replaced by a pneumatic loading pressure which opposes the valve loading pressure and is commonly applied directly on the opposite side of the diaphragm. Thus the net effective positioning force at any point is the diaphragm area multiplied by the differential pressure across the diaphragm. A valve positioner is necessary in order to obtain a corresponding stem position for every value of instrument output pressure.

In one type of springless diaphragm motor, the under side of the diaphragm is statically loaded with a constant pressure from a manually-adjusted reducing-relief type regulator. The top side is automatically loaded through the valve positioner to the pressure required to hold the stem at the position dictated by the instrument output pressure. The exact amount of static loading pressure is determined by the

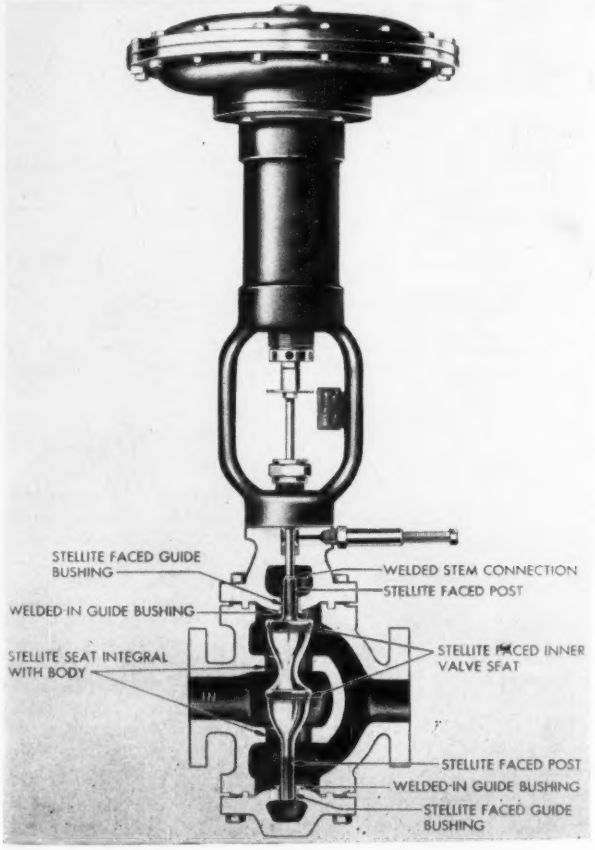

Fig. 10. Control Valve with Hard Surface Internal Trim.

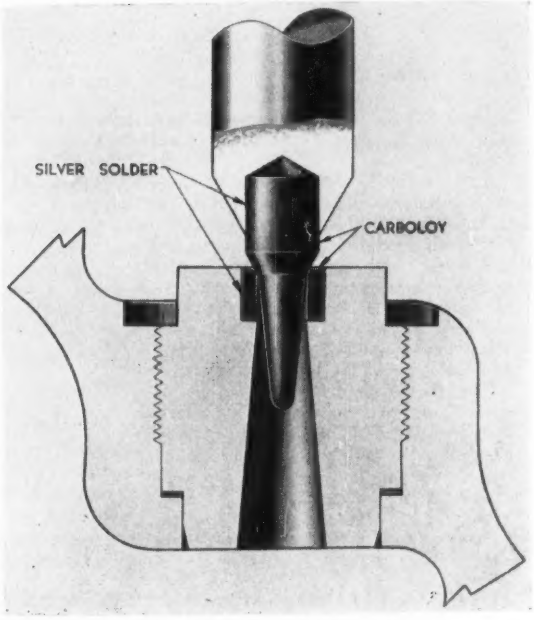

Fig. 11. Carboloy Plug and Seat.

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application and, once set, is fixed by the manual adjustment. If unbalanced stem thrust is downward, the under side is loaded to balance this thrust and the positioner applies lower pressures to the top side to raise the valve stem. If unbalanced stem thrust is upward, the underside is loaded to only a nominal value, say 5 psi., and the positioner applies higher pressures to the top side to push down the valve stem. One limitation of this type is that the maximum force, which is equivalent to the full supply pressure differential of 25 to 30 psi. across the diaphragm, is available in only one direction, depending upon whether the under side is zero or full supply pressure loaded. For any under-side loading, the maximum thrust is equivalent only to the 2 to 1, the sum of the top- and underside pressures is constant and always equal to the spring load divided by the smaller area of the reversing relay. The spring load is adjusted so that this sum is equal to the positioner and relay supply pressure, usually 30 psi. If unbalanced stem thrust is upward, the reversing relay unloads the underside chamber to 0 psi. if necessary, as the positioner loads the top side chamber to maximum supply and maximum downward force is attained. If stem thrust is reversed, the maximum force is likewise available in the upward direction. When the valve stem has reached the position dictated by the instrument output pressure, the top- and under-side pressures stabilize to that point where their difference

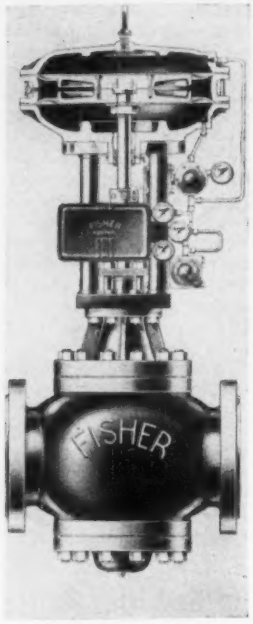

Fig. 12. 8-inch Control Valve with Springless Diaphragm Motor.

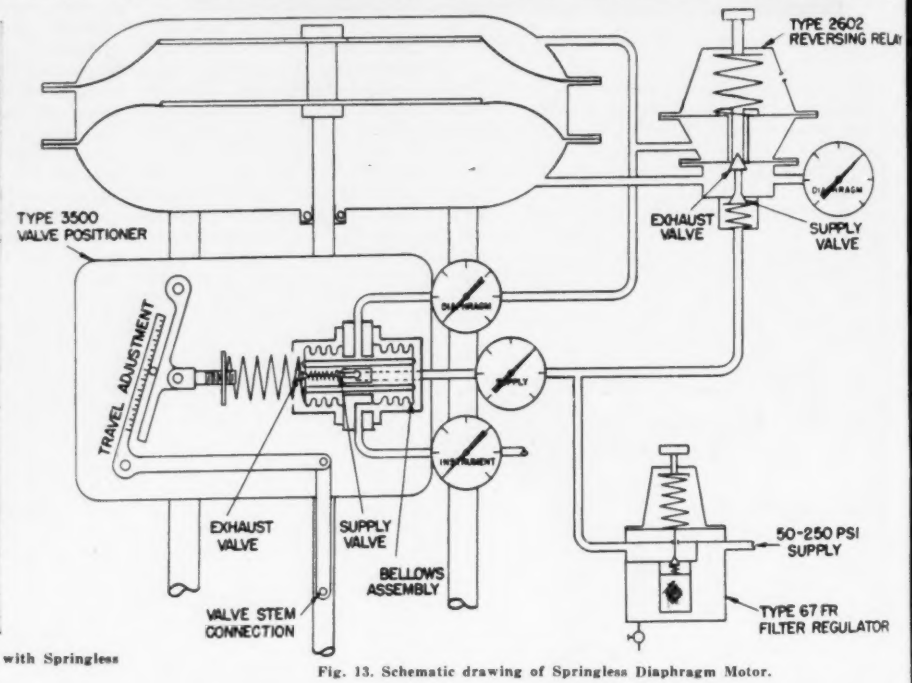

Fig. 13. Schematic drawing of Springless Diaphragm Motor.

temperatures of saturation or superheat. The erosive action of wet gases and fluids carrying entrained solids is greatly magnified at high-pressure (high-velocity) drops. Mention has already been made of this in discussing valve trim.

In gas field operations, reducing the pressure of natural gas from well pressures of thousands of pounds per square inch, with pressure drops of a thousand psi. or more, introduces the problem of freezing in the valve body. If sufficient water is present in the gas, the temperature drop due to high-pressure expansion is sufficient to cause the formation of hydrates which freeze along with free water, and plug globe type bodies. A partial solution to this problem has been found in applying angle type bodies, which have less tendency to freeze and plug by reason of allowing the gas to expand almost directly into the downstream piping. This keeps the zone of coldest temperature away from the body and freezing in the valve is reduced.

A particularly troublesome problem in high-pressure steam and condensate applications is the action that occurs which results in loosening of seat rings and guides and severe corrosion of the internal parts. This is undopbtedly a consequence of the pH and the acceleration of corrosive action by high temperature and high velocities. To combat these effects, all alloy and stainless steel valves have been used, integral seats hard faced along with guides and plugs have been effective, and angle type bodies to reduce turbulence effects have been successful.

difference with supply pressure and then only in the direction of least pressure.

Another, and more versatile, type of springless diaphragm motor is shown mounted on a large valve in Fig. 12. In this version, the loading to the under-side diaphragm chamber is automatically set by a reversing relay in accordance with the thrust requirements and positioning of the stem. Maximum force is available at any stem position and in either direction.

The operation of this diaphragm motor is shown clearly in the schematic diagram, Fig. 13. The reversing relay is arranged to admit air to the underside diaphragm chamber as the top-side diaphragm chamber is unloaded by the valve positioner, and vice versa. Since the ratio of the large diaphragm area to the smaller diaphragm area is acts in the proper direction and amount to balance the stem thrust, and equilibrium is attained.

Diaphragm motors of this type are available to handle stem thrusts up to 5000 pounds, with supply pressures of 30 psi. This has greatly extended the usefulness of diaphragm-motor valves in high-pressure application, and particularly the application of single-seated valves of large size for relatively high pressure differentials.

Physical and Chemical Effects

Often, fluids at high pressures and at high velocity flows introduce additional problems related to high temperature and physical and chemical effects as a consequence of their nature and composition. High-pressure steam, for example, means accompanying high

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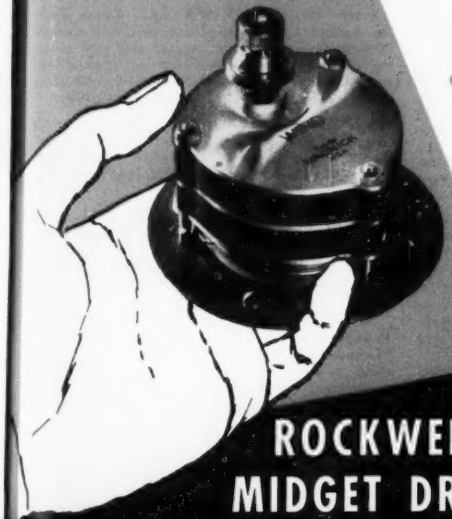

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S-352 STEAM CALORIMETER. 4-page Bulletin 118 describes and illustrates maker's U-path steam calorimeter; covers features, operation.—Ellison Draft Gage Co., 214 W. Kinzie St., Chicago 10, Ill.

S-353 "hp JOURNAL." 4-page Vol. 1, No. 8 issue of this house organ features article titled "Direct Measurement of Impedance in the 50-500-Mc. Range," and describes use of maker's equipment over this range; covers specifications for "Model 803A" VHF bridge and "Model 417A" VHF detector.—Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.

S-354 "TEMPIL TOPICS." 2-page Vol. 5, No. 3 issue of this house organ features article titled "Induction Heating."—Tempil Corp., 132 West 22nd St., New York 11, N. Y.

S-355 PULSE RISE TIME INDICATOR. 2-page bulletin illustrates and describes maker's "Model 632-B" pulse rise time indicator; covers specifications, performance data, features.—Electronic Systems Co., 555 E. Tremont Ave., New York 57, N. Y.

S-356 AIR SAMPLER. 2-page Bulletin CT-8 describes and illustrates maker's "Samplair" for quantitatively estimating the concentration of

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S-358 TRANSFORMERS. 16-page Catalog No. 49A illustrates and describes some of maker's line of "Yeoman" and industrial transformers; covers features and specifications.—Audio Development Co., 2833 13th Ave. S., Minneapolis 7, Minn.

S-359 MODULATING OUTDOOR CONTROLS. 4-page Supplementary Bulletin ST-501 illustrates and describes improvements in maker's modulating outdoor controls; encloses revised chart for enlarged capacity, double-seated valves.—Sarcotherm Controls, Inc., Empire State Bldg., New York, N. Y.

S-360 MAGNETIC MERCURY CATHODE. 8-page bulletin illustrates and describes maker's "Dyna-Cath" high-speed magnetic mercury cathode for the separation of metals; covers features, rates of deposition, operation, construction; lists prices.—Eberbach & Son Co., Ann Arbor, Mich.

S-361 CONTROL LINKAGE STANDARDIZATION. 16-page General Specification CA942 presents control connecting linkage for use with maker's control drives and contains engineering and price data for choosing correct material and arrangement to suit application; permits ordering control connecting linkage and accessories by stock number.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

S-362 "THE BURRELL ANNOUNCER." 16-page No. 50-3-38 issue of this house organ features articles titled "Modern Nephelometry."—Burrell Corp., 1942 Fifth Ave., Pittsburgh 19, Pa.

S-363 AIR-OPERATED VALVE. 6-page Bulletin AU250 illustrates and describes maker's "Electroaire" solenoid air-operated valve; covers features, operation; contains wiring schematic and dimensional drawing.—The Bellows Co., 222 W. Market St., Akron, Ohio.

S-364 DIFFERENTIAL MASTER SENDER. 4-page Bulletin 2150 illustrates and describes maker's meter type differential master sender, a pneumatic device used as metering element in measurement and control of steam, gas and liquid flow, level, pressure differential, etc.—Hagan Corp., 323 Fourth Ave., Pittsburgh, Pa.

S-365 MICROMETER DIAL GAGES & INDICATORS. 36-page Catalog No. 58 illustrates and describes maker's (B. C. Ames Co.) line of micrometer dial gages and indicators; (dial indicator attachments, caliper gages, dial comparators, dial depth gages, dial micrometers, etc.) covers features, ranges; encloses price list.—G. C. Wood, Clark Bldg., Pittsburgh 22, Pa.

S-366 METERING PUMP. 2-page Bulletin 1A-R describes and illustrates maker's "No. 6100" metering pump for hot waxes and cements; covers features, specifications, performance data.—Edward E. Robinson, Inc., 95 Park Ave., Nutley 10, N. J.

S-367 DRAFTING TEMPLATES. 8-page Catalog 50 illustrates and describes 30 templates for use of engineers, draftsmen, architects and designers, also illustrates special templates made to order.—Rapidesign, Inc., Box 592, Glendale, Calif.

S-368 SPRING SCALES & TEST APPARATUS. 60-page loose-leaf bound bulletins describe and illustrate maker's spring scales and test apparatus (dynamometer scales, tensiometers, instrument scales, push-pull gages, etc.); covers features, specifications, applications.—John Chatillon & Sons, 85 Cliff St., New York 7, N. Y.

S-369 FLOW RATE INDICATORS. 8-page Bulletin SC-4.1 describes and illustrates maker's "Flo-Scope" flow rate indicators for air and gas; covers features, typical installations, construction and operation; includes selection table and ordering instructions.—Selas Corp. of America, Philadelphia 34, Pa.

S-370 "MODERN PRECISION." 8-page Vol. 10, No. 1, Spring edition of this house organ features articles on use of maker's products (load controllers, a-c. resistance boxes, tempera-

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S-371 HYDRAULIC REMOTE CONTROL. 8-page Bulletin 20-105 illustrates and describes maker's hydraulic remote control for industrial use; covers features, specifications, applications. —Sperry Products, Inc., Danbury, Conn.

S-372 "GENERAL RADIO EXPERIMENTER." 8-page Vol. 24, No. 11 issue of this house organ features article on maker's "Type 1803-A" vacuum-tube voltmeter. Encloses April 1950 price list.—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

S-373 AIR AND HYDRAULIC POWER. 8-page bulletin illustrates and describes maker's "Gerotor" air and hydraulic valves and cylinders and hydraulic power units; covers features, specifications, advantages.—Rivett Lathe & Grinder, Inc., Brighton 35, Boston, Mass.

S-374 FATIGUE MACHINE. 2-page Bulletin 313 describes and illustrates maker's "Model SF-4 Sonntag" fatigue machine of plus or minus 5000-lb. capacity; covers operation, specifications. —Testing Equipment Dep't, Baldwin Locomotive Works, Philadelphia 42, Pa.

S-375 METERING PUMP. 2-page Bulletin 296 describes and illustrates maker's "Pulsafeeder" piston-diaphragm variable-output metering pump; covers features, applications.—Process Equipment Div., Lapp Insulator Co., Inc., LeRoy, N.Y.

S-376 COOLANT PUMP. 2-page bulletin illustrates and describes maker's "Lubri-King foot-powered coolant pump unit for application of coolant, leaving both hands free; covers features, applications, construction data.—W. A. Horejsi Co., 2001 James Ave., No. Minneapolis, Minn.

S-377 AUTOMATIC GAS-FIRING SYSTEMS. 20-page Bulletin 107 describes and illustrates maker's automatic gas-firing systems for soft metal melting and pot furnaces; includes engineering data and selection tables.—The Partlow Corporation, New Hartford, Utica, N. Y.

S-378 AIRCRAFT CONTROLS CATALOG. 32-page Catalog F-4141 illustrates and describes maker's automatic control systems, actuators, rheostats, temperature sensing elements, micropositioner for aircraft use.—Barber-Colman Co., Rockford, Ill.

S-379 THERMOSCOPIC PENCILS. 6-page brochure Catalog 501 illustrates and describes maker's "Tempilstiks" thermoscopic pencils for determination of working temperatures; covers features, applications; also covers maker's thermoscopic pellets and lacquer.—Tempil Corp., 132 W. 22nd St., New York 11, N. Y.

S-380 "THE C-D CAPACITOR." 16-page Vol. 15, No. 4 issue of this house organ features article titled "Checking Capacitors at Radio Frequencies"; also includes regular section "The Radio Trading Post—A Free Market-place for Buyers, Sellers, and Swappers."—Cornell-Dubilier Electric Corp., Hamilton Blvd., South Plainfield, N. J.

S-381 PIPE-LINE RECORDING THERMOMETERS. 6-page Bulletin T843 illustrates and describes maker's pipe-line recording thermometers for natural gas and manufactured gas temperatures; includes features, typical chart record.—The Bristol Co., Waterbury 20, Conn.

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S-383 STANDARD VOLTMETER, MILLIAMMETER. 2-page bulletin illustrates and describes maker's reference standard d-c. voltmeter and reference standard d-c. milliammeter; covers features, construction, scales.—Sensitive Research Instrument Corp., 9-11 Elm Ave., Mount Vernon, N. Y.

S-384 "THE OHMITE NEWS." 2-page April issue of this house organ features article titled "Rheostat Size Decreased by Tapered Windings," also items on maker's rheostats, resistors, tap switches, etc.—Ohmite Mfg. Co., 4835-41 Flournoy St., Chicago 44, Ill.

S-385 AUTOMATIC VALVES. 8-page Bulletin 283 illustrates and describes maker's new and improved pressure reducing and regulating valves and automatic reseating relief valve for temperature and pressure; covers features, specifications, capacity tables.—A. W. Cash Valve Mfg. Corp., Wabash and Morgan, Decatur 60, Ill.

S-386 "TAYLOR TECHNOLOGY." 28-page Vol. 2, No. 4 issue of this house organ features articles titled "Instrumentation Reduces Cost of Wool Scouring," "A Fluid Cat Cracker 'Runs on Instruments'," "Complete Control for Tire Vulcanizers," and others.—Taylor Instrument Companies, Rochester 1, N. Y.

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